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ON THE NECESSITY AND VALUE OF SCIENTIFIC RESEARCH IN NAVAL ENGINEERING MATTERS AS RELATED TO THE U. S. NAVY, AND THE NECESSITY OF AN ENGINEER TRAINING FOR THE YOUNGER MEMBERS OF THE ENGINEER CORPS OF THE U. S. NAVY.

BY PASSED ASSISTANT ENGINEER F. C. BIEG, U. S. NAVY.

The writer, as many other engineer officers have done, has often deplored the want of some place where engineering experiments could be carried on in a thorough and scientific manner, where the numerous problems confronting our profession could be properly investigated and the interests of the Navy thereby advanced. A few of the more important questions that have from time to time arisen have, to the credit of a small, energetic number of naval engineers, been solved in a measure sufficient for the needs of the hour, even under the disadvantages of the other frequent demands of the Service and of no funds or suitable place for experimenting. A few results valuable to the Government have been obtained by engineer officers stationed at navy

yards, by taking advantage of rare opportunities, and generally in addition to their numerous regular duties. Again, work started on some research, the results of which would have saved much money, has been interrupted or stopped by the transfer of the officer to other duty, a condition which has become of frequent occurence, owing to the small number of engineer officers. But these attempts were only make-shifts, and had they been carried on as the writer proposes, failures would have been prevented and money saved. It is not intended to refer in this paper to the valuable and necessary work done by the Experimental Board, to whom are sent all patented articles and devices for test, before their adoption for naval uses, but only to original investigation and research. The time of the Experimental Board is too fully occupied with its regular duties to leave any opportunity for such work as the writer has in mind.

Many of us have thought of problems, (or they have been presented to us during our sea and shore duty) which should be tested by experiment, but knowing the seeming impossibility of ever having time or opportunity to make these tests, have allowed the subject to pass from our thoughts. It is very much to be regretted that no opportunities have recently been given for doing such work as made Isherwood's Experimental Researches famous, and practically laid the foundation of marine engineering practice for the world. The writer believes that the present occasion, when the Navy and the Engineer Corps have been so brilliantly successful in the design of naval machinery, is not inopportune for bringing this subject before the members of this Society, in the hope that a discussion, showing the value and necessity of a properly-equipped Engineering Experimental Station or School, may lead to its adoption. Every engineering school is supplied with a laboratory, not only for the instruction of the students, but for the experimental uses of the professors. The valuable results of the researches of Prof. Thurston at Cornell University, of Prof. Peabody at the Massachusetts Institute of Technology, of Prof. Denton at the Stevens Institute, and of many others too numerous to mention at this time, are too well known to need more than passing notice. These researches are

carried on by private means, and the results are generously published far and wide, and the Government has not been slow to take advantage of them. As we all believe in the old teaching that "It is more blessed to give than to receive", it seems to the writer that it would be proper for the Government to undertake many of these researches and, while profiting by its own results, let private institutions and persons partake of the advantage. There are many naval questions which the Government can solve, and from the solution of which it will reap a direct benefit, which are entirely beyond the means of private parties.

England has one such station as the writer advocates, devoted however only to one branch of the subject. How much actual money has been saved owing to the chemical researches on boiler incrustations by Prof. Lewes of England, can hardly be estimated.

The writer's outline plan for an Engineer Experimental Station or School, or whatever other name be chosen, is the following:

The School should be at some place where there is still and deep water, (as many of the experiments will be made with boats) and at a reasonably convenient distance from the manufacturing and engineering centers. There should be an engineer officer of rank in charge, under the immediate direction of the Chief of the Bureau of Steam Engineering. To put this school in a navy yard, where the officers attached to the yard are subject to all kinds of duty, would load it with useless routine and be disastrous to good results. As the experimenters are to be engineer officers, it would be just as well to encourage *ésprit de corps* and stimulate the efforts of individual engineers by putting them directly under officers of their own profession, thoroughly conversant with the engineering needs of the Service. With the officer in charge, who might be styled the Director, should be associated two or three officers, whose duties will be defined further on. The number of officers will, of course, depend on the other demands of the Service. The testing outfits and apparatus for the standardization of indicators, gauges, and other instruments, now at the New York navy yard, should be kept at this School.

Whenever an engineer officer has a plan for the investigation of any subject in practical engineering, chemistry, metallurgy, on propellers, lubrication, boiler deterioration, or any of the many other points directly connected with or useful to naval engineering, he would submit it to the Chief of the Bureau of Steam Engineering, through the regular channels, giving his ideas and the scope of the investigation as fully as may be necessary to a clear understanding. Should the Bureau approve his plan, or think the matter worthy of experiment, the officer would then be detailed to the School, as soon as the exigencies of the Service permit. In case of approval, no radical change in the applicant's proposed method of investigation should be made, as he should be given credit for his ideas and allowed to carry them out in his own way. Should any change in the method or the subject be deemed advisable, the applicant should be notified before the plan is approved. There is no use in ordering any one interested in a particular subject to investigate it in any radically different way from his own, for it deprives the experimenter of that personal interest without which there will be no success. Should the Bureau or the Director at any time wish to make original tests or experiments, engineer officers could be ordered as at present, if any are necessary in addition to the officers stationed at the School.

In connection with the experimental part of the School, the writer would suggest a course of instruction for the Assistant Engineers just after their promotion from Naval Cadets. Instead of the present way of allowing these young officers to pick up what information they can at the New York navy yard, where the senior engineer officers are more than sufficiently occupied with the regular work of the yard, they should be sent to the proposed school for instruction. The Director and the two or three officers composing the faculty, should act as the instructors. A properly prepared course of lectures on the management, care and repair of machinery, the estimating of work, &c., aided by the practical work of trial trips and assisting in the experiments, and extended visits to large ship and engine building firms, would fit these young officers for their duties on board ship and give them

the knowledge which they might not pick up by themselves in years. These lectures should be so arranged that, while imparting facts to the students, their minds would be directed and trained to put to practical use in the Navy the information received. It seems to the writer that it would be much more advantageous to the Government and more beneficial to these young officers to order them to a course of instruction, such as here proposed, than to send them abroad to study at foreign schools. With the foundation of a good, practical engineering education, such as would be given by our officers—of whom it may be said in general, that they are the best existing combination of theory and practice—these young engineers would later on be much more efficient as attachés to our legations, in which position they would do important duty as knowing observers of foreign practice. The duty as assistants to the experimenters would be of the greatest benefit to these young officers and enhance their value to the Service; it would not only make them scientific and careful experimenters, but it would lead their thoughts in the direction of observing and studying engineering phenomena during their tours of sea service.

Surely, with the present system of appointing Assistant Engineers, some such plan of a post-graduate course of instruction, as outlined above, becomes an absolute necessity, and would be only justice to the new appointees. The education given at the Naval Academy must be supplemented, if the Navy is to have engineers who can be of assistance on their first cruise as commissioned officers.

In addition to the other functions of the School, the writer would add the collecting of an engineering museum. A systematized collection of engineering models, metals, instruments and supplies would be of the highest value, not only to the students at the School, but to the Navy Department and the older officers.

The founding of such an institution as proposed will prove a profitable and inexpensive investment for the Navy, excite individual efforts to brilliant results, and carry on, systematically and intelligently, the excellent work of Isherwood, Loring, Thurston, Emery and other American Naval Engineers.

Discussion.

Chief Engineer B. F. Isherwood, U. S. Navy.—No more judicious proposal in the interest of the Navy particularly, and in the interest of engineering science and practice generally—which latter, taken in a broad sense, is really the great interest of the world at large—could be made than that of Passed Assistant Engineer F. C. Bieg, U. S. Navy, for the establishment by the Navy Department of what may be called an Advanced School of Experimental and Scientific Engineering in its special application to the purposes of the Navy.

There would be no difficulty in getting Mr. Bieg's proposal put into practical execution were the necessity of submitting all problems in physical science to the arbitrement of direct experiment well understood, for no abstract solution can be accepted as final until it has received a concrete confirmation. In fact, the only reason for accepting such solutions in even the simplest cases, is that they predict the facts obtained by physical measurements when sagaciously made. For positive, infallible information, the appeal must be made to Nature, and must be addressed to her in her own language, that is, experimentally. When the question is so put, the answer will have no uncertain sound; it will be instantaneous and decisive; it will be in harmony with the entire system of physical laws of the universe; it will be the fruitful mother of other series of valuable facts, and it can be confidently applied.

In the Navy, whose ships, comprising hull, machinery and ordnance, may be taken as purely engineering, and whose expenditures for these constructions may be called immense, the importance cannot be exaggerated of having every question capable of experimental answer so answered before expending the money, and perhaps expending it for inferior articles on which, at some future time, the prestige, the interest, the honor and, possibly, the safety of the country will have to be staked.

One of the curious features of human nature is the difficulty of making it understand the value of securing a safe expenditure of a large sum by the sacrifice of a small sum; it objects to the

expenditure of the small sum because an immediate tangible result is not produced, and will squander the large sum in all the self-sufficiency of ignorance without knowing whether the expenditure is judicious or not; it cannot understand that the small sum is a trifling insurance for the large sum. This feature is illustrated in the fact, common to all navies, that a new vessel having been constructed, is *never* properly experimented with to ascertain its qualities, that is, its merits or defects, in order that in future constructions the one may be adopted and the other avoided. There is not a navy in existence whose practice does not show every day expenditures of enormous sums on nearly worthless designs, and which might have been prevented by wisely substituting the lessons of experimental science for the crude notions of complacent folly. The man who does not know, and does not know that he does not know, will never be guided by the man who does know, and knows that he does know.

Whatever valuable experimental work has been done in the navies of the world, and in this respect our own is far in advance of all others, has been effected by the unaided efforts of individual engineers struggling against stupid inertia or actively jealous opposition, without appreciation, encouragement or reward, and solely for the furtherance of professional information and of the discovery of those physical truths so interesting to all highly constituted minds. Even these efforts, valuable as are their results, and made under the most adverse circumstances, would have had a greatly increased value had those who made them been properly supported and furnished with the necessary means and instruments. The proposal of Mr. Bieg is for supplying these deficiencies by the institution of a proper and thorough system of experimental research in naval engineering of the most difficult and delicate problems; and, also, of scientific research, for the latter is the outcome of the former, and must be based upon it. In other directions the advantages to the Navy would be equally important in the education of a highly developed class of engineers combining practical knowledge with scientific methods; a class of officers of strong and independent

character in the proper sense of that word, as well as of great professional qualifications, whose sound judgments, honest purposes, extensive information and incessant supervision could be relied on by the Navy Department to design, construct and manage the machinery of its vessels. As such an education would qualify its possessors far beyond the comparatively narrow boundary just mentioned, the services of so accomplished a class of technical officers could always be employed by the Department on all construction or purely technical subjects with immense advantage to the public service. As a mere matter of common sense, the importance to a great department of the Government of a highly trained body of specialists must be evident, and such a body cannot be produced in any other way than by the act and under the control of the Navy Department. The sporadic work of a few gifted individuals can no more compensate the efforts of a large, compact, trained body acting under a well devised system of instruction and experience, than the brilliant performances of a few heroes can equal the results of a thoroughly drilled, armed and disciplined mass of regular soldiers. Such a body will always supply geniuses enough to lead them.

If it be asked what there is for such a class of specialist officers to do, the answer is, everything that relates to the construction and engineering management of a naval vessel from, not the keel, for there is none any longer, to, not the truck, for there are no longer either spars, rigging or sails. The sailing vessel and the sailor have vanished from the navies of the earth, and almost from its commercial marine. The substitution of exact experimental knowledge for "rule of thumb," of the laws of nature for ignorant caprice, of mathematical demonstration for guesswork, are what is needed, and these can only be had by some such means as Mr. Bieg proposes. The experimental school of engineering recommended must, above all things, be under no other direction than that of its own instructors. The ridiculous fatuity of putting persons who do not know in command of persons who do know must not be repeated if wheat instead of tares is to be gathered. The saving in the cost of a first class naval vessel under the system in question, would pay

the expenses of the proposed school for many a year, besides guaranteeing that the qualities of the vessel when constructed would be all that could possibly be obtained from the dimensions and material employed.

To insist on such considerations at the close of the nineteenth century, with the public intelligence so conspicuously displayed in so many germane directions, seems like furnishing a very unnecessary demonstration of the multiplication table. They are made, however, in the hope of aiding in the sound patriotic work of obtaining for the Navy not only cheaper but better vessels, to indorse the very excellent suggestions which Mr. Bieg has made on an important subject, too long neglected, and to call attention to the fact that a practical realization of these suggestions would be greatly beneficial. They cannot be ignored without incurring the consequent and, under easily conceivable conditions, very considerable injury.

Passed Assistant Engineer C. H. Manning, U. S. Navy.—I think Mr. Bieg's scheme an excellent one, and that it should receive the support of every engineer officer in the Service. Experimental research is one of the best educators that a young engineer can have, and by utilizing the station as a school for a post graduate course and at the same time as an engineering experimental station, two great needs of the service would be filled.

Few besides those directly connected, either as pupils or as instructors, with the Cadet Engineer course at the Naval Academy, appreciate the influence which even the short life of that course has had on scientific steam engineering in this country. The same spirit that made that course what it was is alive in the Engineer Corps to-day, and, if given an opportunity such as this station would open, would bear fruit that not only the naval service, but the whole country would be proud of.

Such a station should be under the direct and exclusive control of the Engineer-in-Chief, subject only to the Secretary of the Navy; but its benefits should be open to all branches of the Service—it should not follow in the wake of some of the other service schools, open only to the elect.

Chas. H. Haswell, C. and M. E.—In the paper under consideration the writer suggests that the Government furnish an edifice designed and equipped for making experiments in engineering structures and operations, and the investigation of problems in physical engineering.

Now whilst I fully concur in the propriety of any method or course by which scientific knowledge could be imparted to the members of the Engineer Corps, or attained, whether by study, observation or experiment, I do not fully concur in the expressed value or importance of experimental engineering, as distinguished from practical, other than to obtain values, direct or comparative; inasmuch as I hold that a knowledge of physical laws renders experiments very generally unnecessary; as a mechanical design or construction that will not withstand the ordeal of physical reasoning, will not sustain itself in operation. It so occurs that in a professional experience of sixty-five years, I cannot refer to a case where I considered an experiment in a mechanical design necessary, and excluding chemistry, very rarely in a physical one.

To obtain relative or comparative value of a structure or instrument, however, in view of the great interests involved in the cost and efficient construction of marine engines and boilers, I am of the opinion that the suggestions submitted are well worthy of elaboration and approval.

In connection with this experimental edifice or school, it is also suggested that there should be instituted a course of instruction for engineers (Assistants) just after their graduation from the Naval Academy. Would it not be better for them to receive this instruction before graduating, and to include in it some "shop teaching" and "engine running," even if the academic term was lengthened?

Regarding the course to be imparted at such a school, I am of the conviction that it is neither by reading or lectures that Cadets or post graduates from the Academy are to be materially advanced in the practice of their profession; for there is more than academic knowledge and observation of experimental mechanics that is necessary for proficient steam engineering.

One does not acquire by a lecture proficiency in determining the condition under which a "hard patch" in a boiler is necessary, and a "soft" one is practicable; how to set an eccentric; stave an air pump; manage an engine in operation, when the vessel is in a narrow or tortuous channel or on a lee shore, and all outboard injections are clogged up with sand or mud; the use of a "snake bellied" gasket; that a pine wood wedge is the very best article to stop a leak in a boiler (it being in operation); or how to part or core a pattern for a metal casting, and that to shorten a wrought iron rod (as a connecting rod) for a short length, it is necessary to add more to the weld than is cut out between the ends of it, etc., etc.

That a school embracing the general features of that proposed would be highly beneficial to the Corps, and incidentally to the Service, there cannot be any question; but the scope of it requires consideration, as it should be borne in mind that *nihil simul est inventam aut perfectam.*

Professor W. F. Durand.—The purpose of this paper is one which must strongly commend itself to all who believe that successful engineering involves something more than a blind copy of the past.

There is no use in attempting to disguise the fact that engineers are called upon to design within a region of uncertainty wider or narrower according to the circumstances. Physical knowledge is not, and from its nature cannot be, absolute. We can only know physical phenomena between certain limits, and it is only as experience accumulates that the limits may be narrowed. We may be certain in looking at any piece of machinery, for example, that, as a mere question of fact, the material is either redundant or deficient; it is not properly shaped and proportioned; and very probably its whole office might better be taken by some entirely different combination of elements. While from the standpoint of absolute knowledge such statement is safe, the point is to determine where the material is redundant or deficient, what dimensions or proportions might be changed, or what change might be advantageously made in the fundamental character of the mechanism, or of its mode of operation.

Advances in this direction are dependent almost entirely on the accumulation of data from experimental investigation.

We must remember that the ideal scheme for experimental work must always involve the provision for the determinate variation of one, and of one only, of the numerous variables which may affect the phenomena in question. Only under such conditions may we intelligently correlate the change in the phenomena with the change in the conditions. In addition, experimental work naturally requires expensive and delicate instruments, trained observers, abundance of time, and experienced direction.

It is evident, therefore, that in the natural course of events, the proper experimental investigation of a subject will rarely be accomplished by the observation of the phenomena arising in the routine of actual service. Very much might be and is done in this way, but it is plain that usually the condition of restricted variation of variables and the best facilities for observations are not present, and furthermore that the ground naturally covered in this way will be only a small part of that required to make the investigation exhaustive and conclusive.

The only way in which the limitations of uncertainty within which the engineer must work may be narrowed is, therefore, by systematically directed experimental investigation, in which the investigation is the fundamental business, and not an incident of regular service.

Again there are wide fields of experimental work, as suggested by the author, opportunities for the investigation of which would never arise in actual service. Only by organized and regularly directed effort can such subjects be reached.

It is perhaps unnecessary at this point to speak of the details of experimental plant, organization and administration, or of the various fields in which experimental work might advantageously be carried on. If the opportunity should present itself for the establishment of such an experimental station, the same genius and fertility of resourse which have already dealt so successfully with engineering problems connected with our Navy will doubtless deal likewise with all such matters.

It may, however, be suggested that in some way there should be provision for some kind of continuity of administration and work. Nothing could suffer more from frequent changes in the officers of administration and operation. While much may depend on natural endowment, it is certain that no one can become a successful experimenter or investigator by inspiration or meditation. No man, however brilliant, can as an investigator do justice to his own mental equipment without a very considerable amount of actual experimental practice. Officers ordered as assistants would necessarily have to spend much time in work of this character before they would reach satisfactory development as investigators, and the unfortunate results which would follow too frequent changes in personnel are only too plainly evident.

The proposition to use such a station for educational purposes seems also worthy of the highest approval. There would seem to be no possible doubt of the value of some such course of experimental engineering for young naval engineers. Such courses and such work are now considered a necessary part of the regular course of instruction in mechanical engineering by the leading schools of the country, while as yet they are but inadequately provided for at the Naval Academy.

As a further suggestion, it might be found possible to place the scientific part of all Government trial trips under the direction of such a station, and the whole scientific staff might be drawn from its officers and students. Valuable as these trial trips now are, it is well known that, due to various causes beyond the control of the officers more immediately concerned, they are sadly deficient in scope, being usually restricted to the determination of the fulfillment or otherwise of contract conditions. With a regular experimental station it might be found possible to have all ships ordered through a vastly more extended series of trials under a uniform direction, and with a corps of observers thoroughly familiar through repeated practice with every detail of the operations involved.

The scientific value of the work which might be accomplished by such an experimental station relative to trial data of our new ships, and in the wide field of marine engineering generally,

needs no especial statement to the readers of the JOURNAL. Beyond its scientific value, the financial value would, without doubt, pay the expense involved many times over, even if consideration were restricted to the Navy itself. If, in addition, we consider the value from the industrial and commercial standpoint to the country at large of such a mine of engineering information, it would seem that in no way could the necessary money be better invested.

Though such a movement may meet with many difficulties, it is one which should receive the sympathy and support of all in any way connected with industrial and scientific engineering in the United States.

Chief Engineer Chas. H. Loring, U. S. Navy.—The main proposition of Mr. Bieg's paper cannot fail to commend itself, not only to those closely or remotely interested in matters involved in our own profession, but also to all engaged in the pursuit of any of the numerous vocations of the mechanical engineer.

Primarily instituted for inquiry into the problems that confront the marine engineer, the sequences of the results acquired through the work of such an experimental station, would extend themselves into the realm of all who are working within the range of physical laws, and so become of wide general value.

Large and comprehensive as has been the growth within recent years of our knowledge of the laws that underlie the art and science of our profession, (and for which, as Mr. Bieg says, we are largely indebted to voluntary individual research) there are still many occult phenomena awaiting solution, the interpretation of which will enable us to obviate or evade many destructive and wasteful agencies that now work evil and entail expense.

The needfulness to the economies of our professional work of continued systematic inquiry and research for the solving of these problems, goes without saying. In naval engineering of whatever kind, the unraveling of these perplexities will be of great value in future constructions, and in their subsequent management, and it seems that the National Government might

appropriately, through one of its departments, establish a station for this purpose, without fear of the charge of being too paternal, since it would of a certainty find adequate return in economy within its own expenditures.

W. L. Cathcart, Esq.—While naval machinery, at this time, has reached a stage of perfection which in some lines seems to approach a limit, there is undoubtedly—if steam continues to be the prime motor—a development still in store for it as great as the demand upon it shall be; for the history of all progress is the passing of what seemed limits in their day. Further, the phenomenal growth of electrical power in land service makes it difficult to estimate the part—principal or secondary—which it is to perform in naval work hereafter. These considerations lead to one certainty at least, the demand upon our engineer officers for original investigations of a high order.

Such work requires facilities for experiment and research. The intuitive genius, who has no processes between conception and execution, is not much of a factor in engineering problems. An idea of value presents itself usually in a complicated form, requiring often much thought and skill to reduce it to its simplest terms. It would seem, therefore, that the experimental station proposed is, for results of the greatest value, a necessity and not a desirable adjunct. Such a station might, with advantage, be extended to serve as a post graduate school, in which officers could be trained as specialists, for whom, in the ever widening field of the Engineer Corps, there is ample room.

To know that the cost of maintaining a station for these uses would be many times repaid, one has but to scan the unbroken record of success presented by the small body of brilliant men who have designed the machinery of our modern vessels. In such hands, the proposed station would be of the highest value to the service and to engineering science.

Chief Engineer C. W. Rae, U. S. Navy.—The subject of experimental research is one of paramount importance to the mechanical engineer, and has occupied the minds of all progres-

sive members of the profession since the art first developed itself into a science.

The growth of the modern navy has brought the necessity of this research more prominently to the front, as in this growth problems have arisen, and are continually arising, which can be solved only in this way, and which must be solved if we are to continue in the front rank of naval engineering, a position of prime importance to ourselves, to the Navy, and to the country.

In all undertakings of this nature, if good results are to be obtained, absolute freedom of action is essential. Those engaged in the research must be unhampered, and must give their whole time and attention to the end in view.

In the paper before us, the author has suggested a station, to be fitted expressly for the purpose, and to be under the sole control and management of those most interested. In this he will meet with the hearty support of all who have striven to accomplish certain ends while continually interfered with by the pressure of other and necessary duties. All utilitarian ideas, in so far as regards the construction and repair of existing structures, should be absolutely dissociated from the scheme. It should be purely and simply a station of experimental research, of scientific enquiry, and of study. It should be in charge of the most eminent engineer the corps can produce, and the assistants should be selected for ability alone. It should be equipped in a manner worthy of the end in view, and every engineering problem upon which authorities are divided, and which is capable of solution by experiment, should be settled at once and for all time.

We point with pride to the investigation and instruction carried on at the Torpedo Station; to the improvement in guns and armor made possible by the experiments at Indian Head; to the problems discussed at the War College, the handling of ships and fleets, and the art of war; so we, too, should perfect our part, in order that at the crucial moment the good work of others shall not be rendered futile by our shortcomings.

The present system of appointment and education of our naval engineers is not without its disadvantages. It is advantageous in that they are educated to naval customs, routine and discipline,

and should consequently make good officers. Their purely professional studies, however, are confined to two years, the first of which, owing to other branches studied at the same time and to the fact that all are not preparing themselves to become engineers, may be properly called introductory, although as much is given them as the time allotted will permit.

Until some better system is devised, a post graduate course will be essential, and nowhere could one be given so well as at a station such as is suggested by the author of this paper. Even should some better method of appointment and instruction be devised, such a course would still be of incalculable benefit to the Navy.

The majority of young men develop professionally after leaving the Naval Academy, after the occasion for that close application to study such as is essential to the full growth of their ambition has passed, and unless some such opportunity be given them, the best efforts of their minds will be lost to the Service.

Our most successful engineers to-day are those of the highest training and culture, the exceptions being those who are successful in spite of their lack of it, and who possess that inborn faculty which would make them leaders under all circumstances. They realize their deficiency and rise above it. All men cannot do so.

It behooves us then to take the material we have, and to develop it to its greatest extent, and in order to do so, a scheme such as that laid out by the author of this paper becomes an absolute necessity.

Passed Assistant Engineer F. W. Bartlett, U. S. Navy.—I am heartily in favor of the excellent plan proposed by Passed Assistant Engineer Bieg. During the last two years, my time has been almost entirely occupied with instructing at the Naval Academy the cadets who have selected, or who have been selected for, the engineer division, and the endeavor has been made to give them in one year as much engineering as possible. The result is an excellent course, as arranged a few years ago and added to or revised each year, for the time allotted; but it is

merely a skeleton of instruction, the filling out to be gotten by the cadet as it falls in his way on duty.

Of experimental work, there is time for almost none, even of the most elementary kind, only a few drill periods being devoted to setting of valves, testing gauges, etc., as there is little enough time for the cadets to get a smattering of the machine work they should know.

All but this skeleton must be acquired haphazard as they are ordered about on duty. Little can be done during the short cruise taken while at the Academy, as only three days are allowed for visiting one ship-building establishment. Here again a very spare skeleton can be given them of the plant, tools used, methods employed, etc.

So the whole course is a skeleton course, as it must be with the present plan of giving only one year in which to make an engineer.

The post graduate school, as proposed, would be exactly what is required, and would also fulfill the many and crying needs for experimental work that are so well put in the paper by Mr. Bieg.

Assistant Engineer Herman O. Stickney, U. S. Navy.—In his valuable paper outlining a plan for a school of experimental engineering Mr. Bieg says, "with the present system of appointing Assistant Engineers, some such plan of a post graduate course of instruction * * * becomes an absolute necessity, and would be only justice to the new appointees."

He has stated the case clearly, and certainly none too forcibly. I was commissioned an Assistant Engineer with the same training that is now given to naval cadets of the line division, and for a part of my first cruise I was entirely out of my element. It could not have been otherwise, since I had been launched suddenly into a position where I was to perform professional duties of which I had only a faint conception.

To discover the causes of difficulties that are continually confronting naval engineers, both at sea and on shore, and to successfully apply the proper remedies, is a task the magnitude of which is evidenced by the fact often asserted that we age more rapidly than other officers.

Of course, persistent investigation and long experience are necessary, but of equally great importance is it that young engineers be given a deeper foundation on which to build their future; without a good foundation any structure, whether mental or physical, is apt to be shaky. Much valuable time is lost while young engineers are picking up volumes of information that should be placed within their reach before they fairly enter upon general service, where routine duties prevent extended study and investigations.

Good as the course of instruction for the engineer division of naval cadets now is, it can be regarded as but the stepping stone to their life's work.

The experimental feature of Mr. Bieg's plan should be warmly advocated by everyone, for, to quote that eminent engineer, Mr. Seaton, "until very recently most investigations of practical problems connected with the marine engine have been conducted in such a way as to confuse rather than enlighten, and the inferences drawn have been rather in accordance with the desires of those interested than with the facts elucidated by experiment."

Passed Assistant Engineer T. W. Kinkaid, U. S. Navy.—Mr. Bieg's scheme for an experiment station is advocated none too soon, and, although I may not be able to add anything of value to his succinct, but complete, statement of the necessity for such an institution, yet I am glad of an opportunity to applaud the movement. Experience has shown that the best experimental work done at the technical institutions to which the author refers is accomplished by post graduate students, and I believe that our young assistant engineers are capable of bringing to the work such enthusiasm, discipline and intelligence as will surely give results of the greatest value.

The search for a non-volatile lubricant, the transfer and stowage of dust fuel at sea, the successful employment of rotary steam engines, the washing of smoke from torpedo boat boilers (to render the boats less visible) are some of the questions whose minor problems are fit work for an experiment station. Some day it may be deemed advisable to issue to ships and to navy yards a

compact and simple apparatus for coal analysis. There is nothing of the kind now in the market, but doubtless the apparatus could be evolved at an experiment station. The throttling calorimeter is widely used, but, although the best we have, it is not wholly satisfactory, chiefly because we cannot get a fair sample of steam. Here we have a problem towards whose solution the Government ought to perform its share of work.

Some of the best men that have belonged to the Engineer Corps of the navy are now pursuing honorable and profitable careers in civil life. It would be a distinct advantage to the navy, if the establishment of a lecture course at the experiment station would result in the bringing of these men of mark into renewed contact with their former brothers of the Engineer Corps.

As to the probable value of the work of the station in training the younger members of the corps, I believe that very few will dispute it.

Assistant Engineer L. M. Nulton, U. S. Navy.—I think the idea of establishing an engineer experimental school, or laboratory, as given in Mr. Bieg's paper, an extremely good one. It is evident that the necessity for such laboratories exist, or outside institutions or firms, whose sole object is that of making money, would not incur the expense of maintaining them unless there was some benefit in so doing.

Every one knows that problems that have been presented during sea or shore duty have, in the majority of cases, been allowed to pass and remain personally uninvestigated because of a lack of opportunity for such investigation.

A short tour of duty at the New York yard showed how discouraging it must have been to carry on experiments, where the officer I have in mind was obliged to oscillate from one part of the yard to another for different parts of his experiment, watch his opportunity to use this or that piece of apparatus belonging to another department, and, probably, at the moment his results were all collected for arrangement and investigation, be put on some Board requiring him to drop the whole experiment for a while.

I think a course of instruction at this school for assistant engineers, just after their promotion from naval cadets, would be of immense value to them. Some such course is absolutely necessary if, as has been done so far, cadets are appointed assistant engineers who have had the course of study prescribed for the line officers, and who have made their two years' cruise as line cadets, as did those of my own class ('89) who entered the Engineer Corps.

We were the first, I believe, to be sent to the New York yard for a kind of post graduate course. The year spent there was very valuable to me. The officers on duty there did everything in their power to assist us, but they were necessarily occupied with their regular duties, and much more good would have resulted if there had been some one detailed as an instructor, whose duty it would have been to direct our attention to those things we did not know because we had never been brought in contact with them.

Since my graduation from Annapolis, the classes there have been divided and the course for engineers has been revised and expanded in every way; but, with the limited time for the course there, it seems to me that a supplementary course, as suggested by Mr. Bieg, bearing directly upon the practical work they would have from the time they went on board ship as assistant engineers, would result in a benefit to them and to the Service.

This part of the discussion is principally with reference to those who enter the Engineer Corps without having had the regular engineer course at the Academy.

It is my own experience, but it cannot be radically different from the experience of all those who enter the Corps under similar circumstances.

Passed Assistant Engineer Edgar T. Warburton, U. S. Navy.—If through the investigations of anyone who is familiar with the disastrous action on copper piping the cause and prevention were discovered, there would be saved to the Government an amount sufficient for the maintenence of the suggested experimental station for several years, and a serious deficiency in our fine ships would be overcome.

Almost every step in the construction of vessels for the Navy is the result of experiment. The splendid material available for the machinery contributes largely to the success of the boldness and originality of design; but this perfection of material was not attained until, to meet the exacting requirements of the Navy Department, the steel makers improved their products by costly experiments, at the expense of the users, of course, though the ultimate reduction in cost more than compensated for this.

Other materials have been brought into prominent use—the several bronzes, aluminum, nickel steel—all the result of experiment.

While the Government has indirectly borne the expense of much of this experimentation, the Navy Department has not been slow to initiate investigation where there is occasion for it. There is about to be constructed an armored 13-inch gun turret similar to those designed for the battleships, and a test will be made of the effect of the shock of projectiles on the turret machinery.

The wise administration of the Navy Department thus assures successful advance by preliminary investigation, and I presume when the Engineer-in-Chief has a matter of importance requiring experiment the means would be provided; but this would necessitate the organizing of a special Board, which would not have the appliances and facilities which add to the ease and accuracy of investigation.

The need is therefore apparent of a well equipped station, as proposed in the paper under discussion, which would not only stimulate and encourage individual experiment and research, but would form a valuable adjunct to the Bureau of Steam Engineering, relieving the designers of many vexatious matters by placing at their service a small corps of trained experimenters.

There is a demand for higher education; young and old participate in the University Extension course, and the summer school at Chatauqua is thronged with voluntary students, who are seeking knowledge for the pleasure and culture it gives.

During the college month of June thousands of graduates were told, with many variations, that their education had but begun;

to none does this apply more closely than to the young men who were yesterday naval cadets and to-day are assistant engineers.

A two or three years' course abroad is considered desirable for the young constructor, and occasionally an engineer officer has a similar advantage; but we should be in a position to give the instruction at home, and when all need it, it should not be denied.

A summer course of lectures for older officers, similar in plan to the course at the War College, suggests itself as enlarging the scope of the proposed station, to the further advancement of the Engineer Corps and the Navy.

The Government has precedents for such an establishment: the Torpedo Station and War College for the Navy, the Artillery and Cavalry Schools for the Army, would be kindred organizations to the Naval Engineer Experimental Station.

Passed Assistant Engineer A. B. Willits, U. S. Navy.—Mr. Bieg's suggestion is a most apt one indeed, and in hearing it, one is strongly reminded of the many times one has soliloquized on the same subject when problems which could only be solved by extensive and expensive experiments have been confronted in practical experience. No doubt we have all felt at such times the keenest regret from the realization of the impossibility of acquiring the exact information we want on many subjects which could be properly elucidated by some such school as is proposed.

The details of the arrangement of such an experimental station is a subject upon which the members of the Engineer Corps will naturally differ, and a free expression of these opinions will greatly facilitate the drafting of the most feasible plan upon which to base any formal proposition for the establishment of the institution.

For my part, I have always felt that the scope and appropriation for the work of the Experimental Board is too limited, and while I must confess to much ignorance in regard to its duties, I cannot see, from my point of view, why the desired goal cannot be reached through a broadening and extension of the duties and control of this Board, so as to expand an already existing

feature into a far more comprehensive one, and (without introducing a novelty) gracefully make the transition from a Board with but few duties, as in the sense of variety, *but with an excellent title*, to one with a boundary as unlimited as that title would signify. Of course, the construction of this new Experimental Board would have to be rearranged as regards numbers, etc., and to their present work would be added all the new work desired. I would suggest also a careful revision of the scheme for ordering the inventive individuals to conduct their own experiments, as I do not think that is a good idea at all. It would lead to prejudice and non-uniform success, I am sure, and it is not at all necessary. Frequently a very good idea will be presented to the Board by a man who is not at all qualified to carry on the analytic work necessary to prove its practical utility, and there seems to be no good reason why the work should not be perfectly performed by a corps of skilled men with a clearly expressed synopsis from the inventor.

As to the composition of the Board I would suggest: One Chief Engineer, as director; two Chief Engineers, as assistants; four Passed Assistant Engineers; four Cadet Engineers.

The magnitude of the work and its great importance to the service would preclude a lesser number of officers being assigned to this duty, and the Experimental Board as then constituted should be under the direct control of the Bureau of Steam Engineering, and independent of any navy yard or station.

There should be also a skilled chemist of ability as an analyst, and a first class electrician; a fine tool maker and clock work hand, together with fine machine hands for special work. A finely appointed laboratory and a complete machine shop would be necessary, and the museum suggested by Mr. Bieg would be a valuable adjunct.

It might be very wise to include the trials of the new ships (not the work of inspection) in the duties of the new board, as the data would be in the line of work valuable to them.

The cadets could be changed every six months, with possible advantage to them.

The location of the school or board is not so important, as experiments with ships and boats could be arranged for at the nearest navy yard.

Experiments with screw propellers alone, with some of the large new ships, would be invaluable. Trying several forms or sizes on some one of these ships and finding out more than we can do without trials would be of great and practical benefit. Establishing economy curves early in the "life" of a ship, making tests of material and establishing the standard of "best" for ships' use, developing to practical utility the ideas which may be advanced by the "head workers" of the Corps, and which may present valuable features; all these things would show a net saving to the Government beyond that which is conceivable by those who do not count the money wasted through ignorance of the actual cost due to lack of detailed information in this line.

The magnitude of the work included in this scheme is such as to command a liberal appropriation, and there can be no reasonable doubt as to the value of the "returns."

Mr. Bieg deserves a vote of thanks for so ably broaching this matter, and I hope the results will prove a great satisfaction to him.

Passed Assistant Engineer E. R. Freeman, U. S. Navy.—The subject under discussion is certainly one of very great importance to Naval Engineers, and it is devoutly to be hoped that this discussion will lead to some tangible and practical results.

I must, however, take strong issue with the author on his statement that "the education given at the Naval Academy must be supplemented, if the Navy is to have engineers who can be of assistance on their first cruise as commissioned officers." The author's idea must be that it is not to be expected that such instruction as his proposed post graduate course is intended to furnish could be given at the Naval Academy, and in that I fully agree with him; but I certainly cannot agree with him if he also means, as he states, that engineer graduates of the Academy generally are of no assistance on their first cruise, even before they are commissioned officers. At the same time I do not think

the academic course for engineers is what it should be and what it could be, and to prove that, I think I have only to show what it has been, citing in evidence the markedly superior standing which has been taken, both at the Academy and subsequently in actual service, by that class which, in my opinion, had decidedly the best education as marine engineers, and the best edification as officers of a military organization that the Academy has ever given. I refer to the class of '78.

I also fully agree with the author that a post graduate school for young naval engineers should be established, and that it should be entirely independent and untrammeled in its operations. And it seems to me that this might be best accomplished by more firmly establishing the existing Experimental Board of Naval Engineers, and merging it, adequately strengthened in membership, of course, into the faculty of a post graduate college. Its work, as well as the work of its students, would then be both instructive to the latter and also of immediate use to the Service. And, as Mr. Bieg urges, it is, furthermore, most important that the practical information which young Assistant Engineers are now given "the chance of picking up at the New York navy yard," should be obtained under the direction of the officers of this college, and should be extended not only to other ship yards, but also to works where material used in the construction of vessels for the Navy is produced. Just as it has been found of great and all around advantage to institute manual training *in lieu* of the former haphazard, sluggish and altogether unsatisfactory apprentice system in the liberal arts instruction, so it must be even more fruitful of good results to instruct the young marine engineer in the actual practice of his profession in all its branches, rather than trust to the uncertainties incident to the Service, which in many cases eventually bring an officer to conduct operations of which he has only a theoretical knowledge. It is quite impossible that any young officer, during the year of his subordinate service, can get a proficient practical knowledge of all the branches of his profession, although zealous ones may and usually do get a creditably efficient one.

P. R. Voorhees, Esq.—I have read Mr. Bieg's paper carefully, and with great interest. I think it appeals strongly to the best engineering talent of the country, and I further think that the matter therein contained should receive the hearty indorsement of such talent. Not alone will the engineer officers of the Navy receive the benefit of the plan outlined for the establishment of an experimental school, and of a course thereat of post graduate practical instruction for the Assistant Engineers, but the country itself, and the engineering profession at large throughout the world, will be benefited in no small degree by the researches and experimental data which will result from the labors of the school. I hope that the proposal may result in the practical fulfillment of its author's ideas and plans.

Chief Engineer H. Schuyler Ross, U. S. Navy.—I am glad to see that the Council of our Society has taken in hand the subject of an organization to prosecute "research" in engineering matters. This subject should have been acted on long ago. Our Bureau of Steam Engineering has for many years instituted many scientific tests for the benefit of the service, as the opportunities occurred, but there has been no regular organization, other than the Experimental Board, for such purpose. There can be no question as to the need of some organization for this work, as problems are constantly arising in modern marine engineering which need practical solution; but I fear that the difficulty to overcome will be the necessary plant and outfit of the varied instruments so necessary to prosecute accurately the researches as they arise. We have plenty of talent in our Corps to carry out accurately any needed scientific investigations, as well as the ability to devise, adapt and analyze them. The sore need will be the material, as well as the "sinews of war" necessary to maintain a permanent organization. Any scheme of action that will accomplish these should meet the hearty approval of all. Mr. Bieg's plan, if it can be accomplished, will give all that is needed, and should enlist the energetic assistance of all.

Chief Engineer R. W. Milligan, U. S. Navy.—Mr. Bieg has taken hold of two subjects, of which it may be truly said, the

importance of either cannot be over-estimated. An experimental station such as he outlines would more than pay for itself, in information gained, in a very short time. As an illustration of this fact, if such a station had been established years ago, we would not have carried on the pernicious practice of making all the scale possible in boilers, when we thought we were doing the very opposite. The point involved was under discussion among engineers for years before it was finally settled; an experiment of one week's duration at an experimental station would have demonstrated what we all now know to be true, and the money saved the Government would have run up into the millions. Other questions still unsettled could be determined, and numerous ones will, no doubt, spring up in the future.

The post graduate course for engineers is of equal importance, and the necessity for it has been recently emphasized by the appointment as Assistant Engineers of three young men who have received very little instruction in their profession; in fact none at all with a view to becoming engineers.

An ideal place for such instruction would be at some large establishment like Cramp's, under suitable instructors; but this is, of course, impractical, as no firm would care to have the trouble connected with it. Of late, the New York navy yard has been a good place for such instruction, and will be for the next year provided competent instructors be detailed for this special purpose, and to see that time and opportunities are made good use of. But the New York yard, or any other yard, may at any time drop from a "construction" to a "repair" shop, and thus be less desirable than if new work were always in progress. Still, taken in connection with the adjacent private plants, to which short visits could be made, I think it the best place we have, provided the course has proper supervision, and the only thing to interfere with this is the scarcity of engineer officers.

While it may be economical to combine the experimental station and the post graduate school at one station, it is a question whether the results would be as favorable for the post graduate course as they would be if the two were separate. They certainly would not be for some years, or until the experimental station had the proper plant.

Chief Engineer G. B. Ransom, U. S. Navy.—Of late the press has been devoted to the subjects appropriate to the close of the educational year, and many good suggestions relative to intellectual progress have been made in connection therewith. In its broadest aspects, I consider the subject under discussion to be in line with current opinion upon the theory of evolution, and one worthy the most thorough consideration.

The development of power from fuel concerns not only the steam used, in its pecuniary aspect in this steam using age, but it is an intellectual problem—a better solution than any yet offered will mark an era in the advance of civilization as typical as that of the steam engine. In its design and construction the steam engine calls upon the acquirements of the mathematician and physicist, the delineating ability of the draftsman, directly upon the skill of six varieties of handicraftsmen, while indirectly there are but few branches of labor left unrepresented in the finished article; the world is interested in its efficiency.

An engineer, worthy of the title, must be thoroughly informed, not only in regard to theory but in regard to practical work as well. To acquire a respectable position in the profession requires much application; to be a leader in it calls for qualities usually ascribed to genius. An engineering education is necessarily an expensive one, for during the progress of work questions demanding investigation are continually arising, while new applications of theory to practice call for experimental constructions which involve an outlay that the experimenter could not be expected to make. Considering the interests involved, a request for aid in money, books and apparatus, instruction, and opportunities for research, cannot be considered unreasonable. Its extension would be consistent with the action of the Government in regard to objects which, in a financial sense at least, are not of greater importance than the marine steam engine.

The Army has its Engineering and Artillery schools as well as its school for both Cavalry and Infantry. The medical profession is recognized in the costly Army Medical Museum, Naval Museum of Hygiene, and the Naval Medical School at the Brooklyn Laboratory. The naval Line officer is instructed in

ordnance at the Washington navy yard, in torpedo practice at Newport, and in the general principles of his profession at the War College. The suggestion that the Naval Engineers should also in some form combine both study and experiment, needs no argument to support it. Engineering failures in the past have completely demonstrated the costliness of ignorance. I am inclined to go much further in the direction indicated by Mr. Bieg than to simply ask for the detail of two or three members of the corps as instructors, the gathering of a class, and the attempt to establish a marine mechanical engineering laboratory. I would add a Naval Constructor to the faculty, and a professor in chemistry. The course should be systematized, and its satisfactory completion should be requisite for promotion. The class should be composed of ten from each of the two lower commissioned grades, and the duration of the course of instruction should be not less than six months. Those showing special aptitude should be given longer time for the preparation of theses involving original investigations and the statement in proper form of the latest successful applications of theory to practice.

In addition, I would have every member of the corps submit an annual report of his connection with engineering operations. These reports should be properly digested, and those items found worthy should be published. Any member of the corps desiring it should have either an opportunity to experiment directly with an approved process or contrivance, or, if this should not be feasible, his directions should be followed and a report made of the results obtained.

I should be inclined to prefer the navy yard at Boston for the location of this school of application, mechanical marine engineering laboratory and experimental station.

Finally, I would be liberal in extending its privileges to all naval officers desiring them, and should expect that once started its development would be rapid, sufficiently so at least to render it possible for American naval engineer officers to obtain therein a good practical and theoretical preparation for the arduous duties incident to their profession.

Passed Assistant Engineer W. M. McFarland, U. S. Navy. —I am very glad that this subject has been proposed for discussion, for I believe it of the greatest importance, and I am satisfied that if the proper authorities had the merits of the case adequately presented to them, they could not fail to move in the matter. A very slight acquaintance with engineering history will show how absolutely essential to progress is proper experimentation, and instances could be multiplied to prove an absolute saving to the Government if proposed schemes were tried by competent experimenters on a small scale instead of being at once put in use on a large one.

One of the most notable instances of this was the controversy about the use of steam expansively. Our own Isherwood, with rare sagacity, aided by his famous experiments on the *Michigan*, had realized that, with the low pressures in use at the time of our late war ('61–'65), there was an actual economic loss in carrying expansion beyond a very moderate degree, while the weight of machinery was greatly increased. Yet it remained for the actual trial of the machinery of the *Pensacola* to show the utter failure of the ideas of the advocates of extreme expansion.

For many years, all navies committed the absurdity of "blowing down" to reduce the formation of sulphate of lime scale, until Cousté's experiments showed that this was the very plan to cause the greatest amount. We also had the absurdity of boiler corrosion being charged to everything under the sun except the reason which was right under our eyes, the plan of emptying the boilers and opening them *to dry*, really to rust. The researches of the British Admiralty Boiler Committee set us right on that point, and have saved all countries thousands of dollars.

Finally I may mention the experiments on triple screws made by M. Marchal of the French Navy, which led our Engineer-in-Chief to adopt them for the *Columbia* and *Minneapolis*. Had it not been for these, and the application of triple screws on the Italian gunboats in consequence of them, which assured satisfaction in their use, I think it is very safe to say that our two

flyers would have had twin screws and would not have been as fast as they are.

There are many problems awaiting solution which can only come from exhaustive experiments, and these can only be had when some such plan as Mr. Bieg proposes is adopted. And it must not be imagined that these problems are speculative or merely educational. Many of them are of an intensely practical nature, and a thoroughly satisfactory solution would increase the efficiency of our ships and cause a saving to the Government.

The second part of Mr. Bieg's plan, the school for young engineers, is a matter on which I have thought a great deal, and I consider such a school a vital necessity for the efficiency of the Engineer Corps. There is no branch of modern technical science in which there is greater progress or more change than naval engineering, yet our officers are left to "pick up" information as best they can. The very journal in which this discussion is printed was the outcome of the desire of our officers to do what they could, at their own expense, towards keeping the members of the Corps informed of all the latest improvements in our profession. We have already in the Service the Torpedo School, the course of Ordnance Instruction at Washington, and the Naval War College, while the Army has its Post Graduate School for Engineers and the Artillery School. It certainly seems that, if these institutions serve a useful purpose, of which there can be no doubt, a school of application for Naval Engineers would also be useful.

We need such a school now especially, because some of our young officers, through no fault of their own, are coming to us with very inadequate preparation, and something must be done to give them proper training, and I am sure we all realize from personal experience how greatly we would have been benefited by a course at such a school after our cruises as cadets.

Machinery is playing a more important part in our Navy every day, and it is of vital importance to the efficiency of the Navy that the officers charged with its care should be thoroughly trained and competent. Only engineers who are conversant with the facts realize what apparently small things may cause

great losses of efficiency. We must try to convince the authorities of the importance of the proper training of our engineers, and then the school will follow as a matter of course.

Passed Assistant Engineer John R. Edwards.—There has been handed down to the deck officer, for his guidance, a wealth of war experience and strategic literature which must be of great use in working out the solution of problems that confront him. Despite the fact that some branches of his profession are exact sciences, it is considered a necessity that he should receive post graduate instruction at the Washington gun foundry, the Torpedo Station, and the Naval War College.

Naval engineering science is a developing one, and there are many problems to be solved by the Corps of Naval Engineers in their work of designing, maintaining and repairing the machinery of war vessels. The opportunity to acquire such knowledge must be given them, and the establishment of the projected institution would be productive of great results, not only to the Naval Service, but to the country at large.

With the growing importance of engineering science and with public sentiment commending the work of the naval engineer in his effort to make our vessels of war more efficient, this officer finds no reason for excusing his action in taking aggressive measures for the improvement of the Naval Service. There should be established without delay an engineering laboratory and post graduate school, where the full measure of the Engineer's worth could be developed.

Professor Ira N. Hollis.—The plan of establishing a station for experimental and educational purposes should commend itself to the Bureau of Steam Engineering and the Navy Department for two reasons: first, to determine accurately disputed points in engineering; second, to afford additional training to graduates of the Naval Academy. In regard to the first point, there is no place in the United States where the larger questions in mechanical engineering can be examined. The expense is usually too great for private establishments. For instance, there are many doubtful points about boiler construction, such as the

proper stiffening for manholes in the shells, the best shape of the heads and the strength of fastenings between heads and shells, the influence of length upon the bursting pressure, and the effect of the heads upon the strength of short cylindrical shells. These seem to be matters that mathematics and mechanics cannot determine; at the same time they are of great importance to the whole country. While all boiler makers are interested in them, no single firm could undertake experiments on a sufficiently large scale to obtain really useful results. The Government could not put money to a better purpose than to provide for the safety of the thousands of men now engaged in running and caring for the plants scattered all over the country. Every city is filled with mines, often placed beneath the sidewalks, dangerous alike to attendants and passers by. The boiler question is not alone in the demand for experimental work, but the engines and various devices that go into our ships require careful examination. Money spent in experiment is often saved over and over in the subsequent adoption of the most efficient machines.

The group of men detailed to such an experimental school would be useful in other directions too. Smaller Boards could be sent from time to time to ships in commission for the purpose of determining economic results of machines already in use. The log books are practically useless, because no ship has trained officers enough to make the necessary observations and keep track of them. No man can run the engines of a modern war vessel and take accurate data at the same time. No merchant ship company would be foolish enough to undertake it; yet the Bureau of Steam Engineering is forced into this position by the lack of opportunity to train its own men and to detail them to the best advantage. The increase of efficiency and the knowledge gained by three or four additional engineers placed on board a new ship for one year, would more than pay for the extra expense.

This brings me to the second point, that of education. There is no place where such a detail of engineers could gain the proper training for the above work better than in an experimental

station. Our young men come out of the Naval Academy prepared to become engineers. Their education has simply made them ready to study the profession. A post graduate course, after two or three years at sea, would therefore be extremely valuable. It would not only give them the very best training in engineering, but it would bring them, more or less, in contact with men outside of the Service and gain for the Navy an experience with commercial questions which our men would find most useful. There is nothing so deadening to the energies as a number of years spent in a subordinate position upon one of our ships. That Navy is fortunate which keeps alive the interest and zeal of its officers in time of peace. I can conceive of nothing that would afford a greater stimulus than such work as a well equipped experimental station would supply.

It strikes me that one of the causes of our success in designing the machinery of the new ships has been the singular ability of the Engineer-in-Chief to awaken the interest of the younger men in the Corps, and thus to bring out their best work.

The success of the modern ship cannot be attained by one man, however able; it must depend upon the hearty co-operation of the officers serving on board, and anything which tends to enlist their co-operation and make it intelligent will be of the greatest value to our country.

Passed Assistant Engineer F. C. Bieg, U. S. Navy.—I am deeply sensible of the kind consideration given this paper by the members of the Society, and may be pardoned for feeling flattered at the general tone of approval of the discussion.

There are only a few points which require some comment and explanation.

With all due deference to the high authority of Mr. Haswell's statements, I beg to differ in regard to his view of the value of properly prepared lectures as a help to proficiency in the practical work of our profession. While the teachings of personal experience impress themselves more firmly on the mind, I cannot see why the imparting of any one's experience should not help and instruct another who is without that experience. I think one

of Mr. Haswell's own examples, "That to shorten a wrought iron rod for a short length it is necessary to add more to the weld than is cut out between the ends of it", will show how valuable a point can be given in even a short lecture. To gain the above knowledge would cause, under the system of "acquiring personal experience", the ruin of at least one rod, or require a "streak of luck". Much must come by experience, and by experience alone, but whatever those who have had experience can do to prevent the inexperienced from falling into error, should be done, and I am convinced can be done with profit to the Navy and the inexperienced individuals.

In regard to Mr. Freeman's objection, I think it will be found, taking the extract quoted by him in connection with the first part of the paragraph to which it belongs, and the statements of Mr. Stickney and Mr. Nulton, that he has labored under a misapprehension. As one of the class of '78, to whom Mr. Freeman refers, I confess that my services during the first part of my first cruise would have been more valuable to the Navy and to the Chief Engineer of the ship to which I was attached if I had had some such instruction as proposed. I do not for one moment wish to impugn either the intelligence or energy of those young officers who, from Naval Cadets of the Line division, enter the Engineer Corps and upon its arduous and unappreciated duties, but I do say that all means should be employed to give them, in practical, useful form, the results of the experience of their predecessors. They should not be sent out on their new duties unequipped, with the expectation that all they need know they will pick up. I repeat, such a course is neither just to the young officers nor beneficial to the Navy.

In regard to the suggestion that the scope of the present Experimental Board could be enlarged to take in the duties of the proposed station, I think that such a course would be injudicious. The researches, experiments and course of instruction at the station should not be interfered with by any call to other duty except that of war, and, therefore, its location in a navy yard was not advocated. The tests carried on by the Experimental Board are, frequently, subject to conditions of time and

place, depending on the patentee of the article to be tested—conditions which would be disastrous to the usefulness of the station.

It has also been suggested that the post graduate course of instruction might be given at the Naval Academy. It seems to me that the mixing of commissioned officers under instruction, to whom the Academy Cadet rules could hardly be made to apply, and young Cadets would be demoralizing to the discipline of the Academy. Again, to separate the Experimental Station and the Engineer School, would prevent the training with the experimenters which has been advocated.

Unless the proposed Station is established on independent lines, it would be better not to have it at all.

In conclusion, I desire to express my thanks to the members who have taken part in the discussion, and to hope that their valuable suggestions may soon turn the outlined proposal into a welcome fact.

Since the above paper was written, the new Assistant Engineers of this year have been ordered to various ships for duty. The great need of Engineer officers probably has made this necessary; but it is to be hoped, for the sake of the proper training of these officers, that the details will be temporary only.

EXPERIMENTS IN CONNECTION WITH EVAPORATION.

By D. B. Morison, Esq.

[Read before the Liverpool Engineering Society.]

The universal practice on steamships a few years ago was to supply the loss of water due to leakage in a condensing engine from the sea direct to the boilers, but since the introduction of triple expansion, with its higher pressures and temperatures, the necessity for minimizing the scale in boilers has resulted in the use of an independent apparatus, in which sea water is evaporated by means of steam, and the generated steam, being condensed, is delivered to the boilers free from all impurities. Apart from the necessity of such an arrangement from an engineering point of view, there is the commercial consideration of reducing the boiler scaling expenses, minimizing the liability to accidents, and prolonging the life of the boiler, as, whilst it is possible for careful engineers of long experience to work boilers without an evaporator, there are few superintendents who do not realize the fact, that in order to obtain the greatest engineering and commercial efficiency, and as a safeguard against accidents, an evaporator is a necessary auxiliary on board a modern steamship. The quantity of water lost depends on the design and workmanship of the various details subjected to steam pressure, to the number of appliances and arrangements for preventing waste, and to the care of the engineers in charge.

The chief sources of loss in the main engines are from the piston rod, valve spindle and feed pump glands, but these may be minimized by the use of automatic water drainers and special water saving appliances, examples of which are shown on Figs. 1 and 2. Careful attention of those in charge to all the details of the various steam connections is the chief factor, however, as

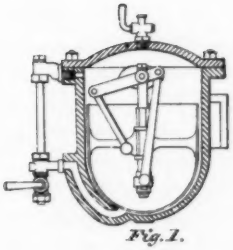

Fig. 1.

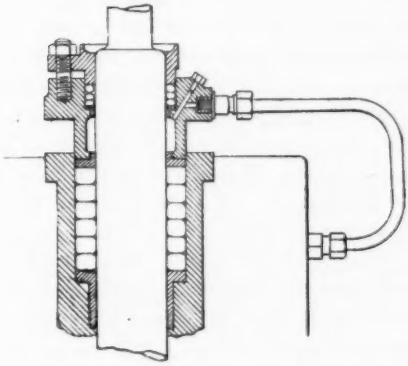

Fig. 2.

there is no better index of the efficiency of an engine room staff than the quantity of auxiliary feed water required.

The ease with which loss of water in marine machinery can be made up, by simply allowing it to flow from the sea to the hot well, has often tended to mislead those in charge as to the quantity which should be required and the quantity actually used. The natural result is that there is a large number of boats in which the loss is most extravagant, the engineers being either unaware of the fact or accepting the condition as normal.

One of the many examples which have come under the writer's notice was a steamer with an evaporator, which, even when coated with scale, would have been capable of producing four times the amount of fresh water which should have been necessary. The engineer reported that the evaporator was certainly of assistance, but he had to keep it going continually, clean it every day, and use, in addition, a large amount from the sea. This is an apt illustration of the unconscious influence the old auxiliary supply from the sea had over the engineer, as his entire efforts were concentrated in endeavoring to compel the evaporator to produce sufficient water to make up the loss, he being totally blind to the fact that the amount of loss was both extravagant and unnecessary. An example of what may be considered an exceptionally high efficiency has been obtained on a steamer belonging to the Peninsular & Oriental Company, on which facilities were kindly given the writer by Mr. Manuel, for obtaining reliable data extending over several voyages. The engines are 28, 44, 72 by 48 inches stroke, with two boilers of 160 pounds pressure, steam steering gear, electric light and the usual auxiliary machinery being fitted.

At sea the average indicated horse power is 2000, and the amount of auxiliary supply five tons per day. In the previous example the indicated horse power was about 1000; each boat was fitted with identical evaporators; the Peninsular & Oriental boat used $2\frac{1}{2}$ tons per 1000 indicated horse power per day, and the other certainly not less than 15 tons, but probably nearer 20 tons. In order to allow a margin for auxiliary engines, it may be assumed that the consumption of water in the Peninsular

& Oriental example is 15 pounds per indicated horse power per hour, and by reference to the annexed table it is seen that $2\frac{1}{2}$ tons is equivalent to $1\frac{1}{2}$ per cent. of the total feed water.

AUXILIARY FEED WATER.

Calculating the feed water at 15 pounds per I.H.P. per hour.		Calculating the feed water at 18 pounds per I.H.P. per hour.		Calculating the feed water at 20 pounds per I.H.P. per hour.	
Percentage of auxiliary feed to total feed water.	Auxiliary feed in tons per day per 1,000 I.H.P.	Percentage of auxiliary feed to total feed water.	Auxiliary feed in tons per day per 1,000 I.H.P.	Percentage of auxiliary feed to total feed water	Auxiliary feed in tons per day per 1,000 I.H.P.
1 per cent.	1.6	1 per cent.	1.93	1 per cent.	2.14
2 "	3 2	2 "	3.86	2 "	4 28
3 "	4.8	3 "	5 79	3 "	6.42
4 "	6.4	4 "	7.72	4 "	8.56
5 "	8.0	5 "	9 65	5 "	10 70
6 "	9.6	6 "	11 58	6 "	12.84
7 "	11 2	7 "	13.51	7 "	14 98
8 "	12.8	8 "	15.44	8 "	17 12
9 "	14 4	9 "	17 37	9 "	19.26
10 "	16.0	10 "	19 3	10 "	21.4
11 "	17 6	11 "	21 23	11 "	23.54
12 "	19 2	12 "	23.16	12 "	25.68
13 "	20 8	13 "	25 09	13 "	27.82
14 "	22 4	14 "	27.02	14 "	29.96
15 "	24 0	15 "	28 95	15 "	32.1

The consumption in the other boat would probably be about 18 pounds, and assuming 20 tons of auxiliary feed, the percentage of the total would be 10.3 per cent. These cases may be considered extremes, but the greatest care is necessary in order to obtain maximum efficiency, as a number of very slight leakages when combined produce a large quantity at the end of 24 hours. The trials of the S.S. "Iona," by the Research Committee of the Mechanical Engineers, may be taken as an example, as the loss was 6 per cent. of the total feed, although beyond a slight leakage at the feed pump glands during a portion of the trial, there was nothing apparent to the many observers on board which would account for such a large loss.

The Committee on Naval Boilers recommend in their Report that not less than six tons per 1000 horse power be allowed, which would be about equivalent to three per cent. of the total feed. This allowance seems very small when the large number

of auxiliaries is considered, but probably the estimate is made on the maximum indicated horse power, which is, of course, very seldom obtained. It will be evident, therefore, that not only does the amount of auxiliary feed vary for different types of engines, but the variation may be very great in ships of the same class, depending entirely on the condition of the main and auxiliary machinery. In passenger boats, where the labor is sufficient to keep everything in good order, a safe allowance is eight tons per 1,000 indicated horse power at sea, which, assuming a consumption of 15 pounds of water per indicated horse power, is five per cent. of the total feed; but in cargo boats, where the available labor is much less and so much attention cannot be given to details, ten tons per 1,000 indicated horse power is advisable. In both these cases there is ample margin for contingencies, and if evaporators are fitted of these capacities but still are not sufficient, then the waste of water is highly extravagant and altogether unnecessary.

The arrangement of multiple evaporators working in series so that the generated steam from the first is utilized to generate steam in the second, and so on, although being the universal system for sugar refining and distilling, is not in use to any extent on shipboard, as it involves unnecessary complication and initial cost, besides entailing more attention when working; so that what is generally understood by a marine evaporator is a single vessel in which salt water is boiled away, the heating medium being steam. From the elementary nature of the apparatus the different designs are exceedingly numerous, as, given a vessel in which water is evaporated by means of steam within a tube, there is ample scope for variation of detail. But simple variation is of no value unless accompanied by definite improvement, which only results from development based on the practical requirements of those engaged in the working of the apparatus at sea; and it is becoming more and more recognized by designers that not only must all auxiliaries on shipboard be simple, but that the labor necessary to maintain efficiency whilst at work must be reduced to a minimum. There is only a certain amount of labor available, and the requirements from

that labor are ever increasing; in fact, if engineers at sea are hampered with any detail which requires an undue amount of attention, then, as a consequence, something else suffers. It is, therefore, practically imperative for success that such an elementary apparatus as a marine evaporator must not only be efficient from a scientific point of view, but also from a marine engineer's point of view, which is equivalent to saying that it must be simple in construction, strong, requiring but little attention when working, and the least possible labor in cleaning. It would be altogether beyond the possibilities of a paper to deal with all the designs which have been proposed, so the writer will refer only to some of those which have been adopted. Long before marine evaporators were introduced, Messrs. Normandy, Kirkaldy, and others, had been engaged in the manufacture of distillers, but it was the well known engineer, Mr. Weir, of Glasgow, who showed the marine engineering world the advantages which would result by the use of what are now generally known as marine evaporators. Mr. Weir's first apparatus was designed in 1884, but his evaporator in its present form was introduced in 1887, and since that date Mr. Weir's lead has been followed very largely. Evaporators may be divided into the following classes, viz., those in which—

(1.) The heating tubes are connected to steam and exhaust chambers within the evaporating vessel, the means of access to the tubes for cleaning or removal being through hand-holes in the sides of the vessel, as, for example, the early designs of Messrs. Kirkaldy, of London, and Mr. Quiggin, of Liverpool.

(2.) The heating tubes are attached to the door in such a manner that on removal of the door the coils can be brought without the vessel for examination and cleaning, as, for example, the designs by Messrs. Weir, Rayner, Kirkaldy (1894), and Mudd.

(3.) The heating coils are attached to the base or lower vessel containing the steam connections, the coils being covered by a dome which, on being lifted, exposes the coils, as in Morison's dome type.

(4.) The heating coils are attached to steam and exhaust chambers within the vessel, such chambers being arranged to

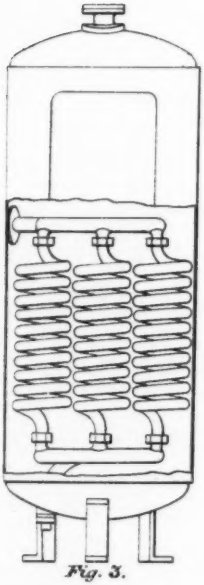

Fig. 3.

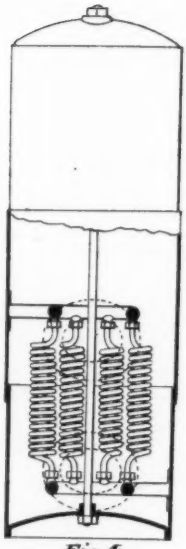

Fig. 4.

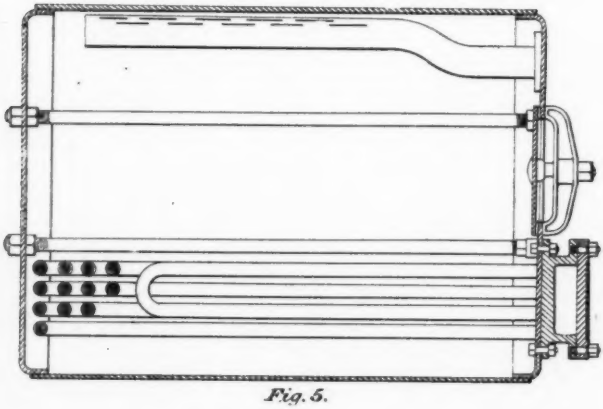

Fig. 5.

terminate in a trunnion, so that each coil can be revolved to a position opposite a door in the side of the vessel through which it can be removed, as in the design by the late Mr. Blair, of Stockton.

(5.) The heating coils are independent of the door, and are arranged on arms terminating in trunnions, so that the entire heating surface can be swung without the vessel into a position for removal or cleaning, as in Morison's radial evaporator.

The early design of Mr. Kirkaldy, the well known maker of feed heaters, distillers, &c., consisted of a vertical cylindrical vessel, Fig. 3, within which were a number of spiral coils connected at their upper and lower ends to brass steam inlet and outlet chambers, access being obtained by two doors, one opposite each chamber. Mr. Quiggin's early design, Fig. 4, is somewhat similar in general arrangement, with special features of detail which have rendered it a very successful apparatus. Mr. Quiggin also manufactures multiple evaporators of very high efficiency, but although multiple effects are used in some large steamships, the system is by no means common.

The well known evaporator of Mr. Weir, Fig. 5, consists of a horizontal cylindrical steel shell with two flanged ends, riveted throughout and fitted with the usual mountings. The heating tubes are of U section and are attached to a tube plate, forming part of a hollow door containing the inlet and outlet chambers. Each tube is flanged at its discharge end, and the diameter of outlet reduced to a minimum in order to maintain the pressure within the tubes and so increase the efficiency of the apparatus. Some very valuable experiments were made with this evaporator by Mr. Lang, who read an interesting paper on the subject before the Institution of Engineers and Shipbuilders of Scotland, in 1889.

Mr. Rayner's design, Fig. 6, consists of a vertical cylindrical vessel; the coils are attached to the door as in Weir's, but are in the form of volutes. Two valves controlling the supply to and from the steam and exhaust chambers in the door are fixed to the body of the evaporating vessel, and connections are made by co-incident ports in the flanges of the door and the

vessel, so that when the door is jointed in position these form a continuous passage. The arrangement is very convenient and does not necessitate the removal of any mountings when withdrawing the tubes. The door and attached tubes are withdrawn from the vessel by a simple overhead runner, the whole forming a very compact apparatus. Mr. Kirkaldy's latest design is very similar in general detail, the coils being in the form of volutes connected to chambers in the door, the volutes being in pairs arranged in vertical planes, and not horizontal as in Rayner's. Another modification is that manufactured by Messrs. Maudslay, as in Fig. 7.

Mr. Mudd has also adopted the same general arrangement, Fig. 8, except that the door is hinged, and U-shaped tubes, in the form of arcs, are struck from the hinge of the door as a center.

Morison's steel dome type evaporator, Fig. 9, is in the form of a vertical cylinder, the lower part or base having attached to it the spiral coils arranged in pairs. The upper portion is in the form of a dome, which on being raised is supported by standards, thus exposing the coils and enabling them to be readily cleaned.

The evaporator designed by the late Mr. Blair, Fig. 10, is in the form of a vertical cylinder with a door in the side. The coils are spiral and mounted on a trunnion base, so that each coil can be revolved opposite the door for examination or cleaning. Morison's radial evaporator, Fig. 11, comprises a lower horizontally arranged water vessel, provided with a vertical cylindrical extension forming a steam dome. The lower part of the vessel is fitted with a door which is swung by a pivoted arm to which it is attached into such a position as will enable the coils to be withdrawn. The heating coils are arranged in pairs, and are detachably connected to two horizontal tubes, forming respectively the inlet for steam and the outlet for the resulting water of condensation. Each of these tubes is closed at its free end, and terminates at its other end in a cap mounted on a hollow plug, so that the tubes and the attached coils can be readily turned on the hollow plugs as a center, and so withdrawn from the vessel for cleaning purposes, and afterwards swung back again, these operations being affected without breaking any steam connections.

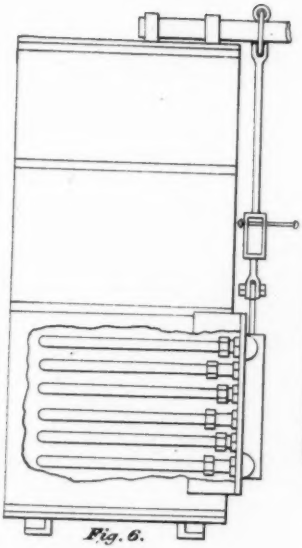

Fig. 6.

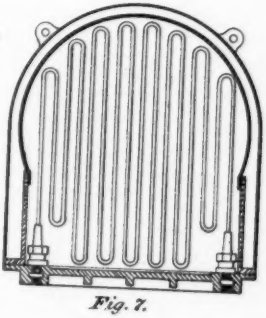

Fig. 7.

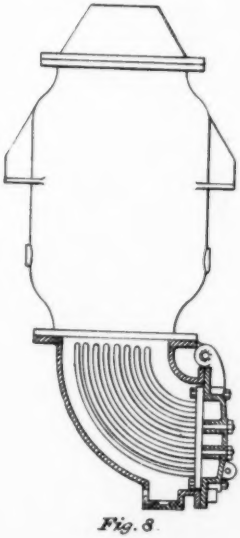

Fig. 8.

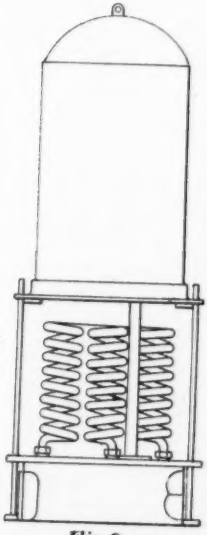

Fig. 9.

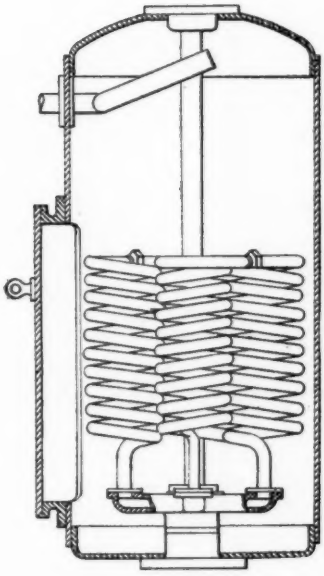

Fig. 10.

Fig. 12.

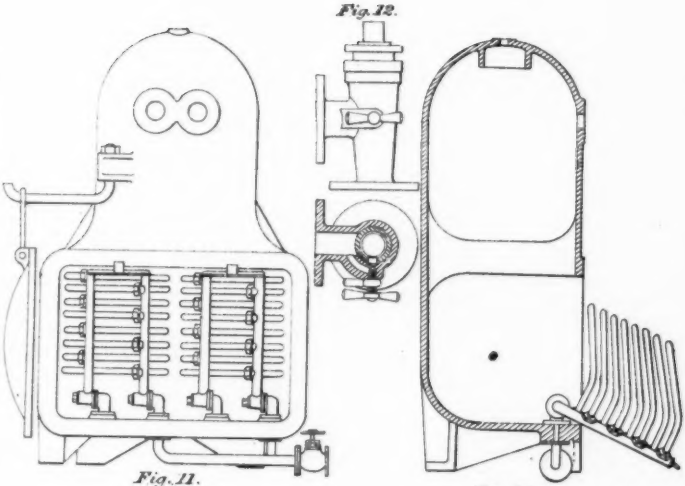

Fig. 11.

Fig. 11a.

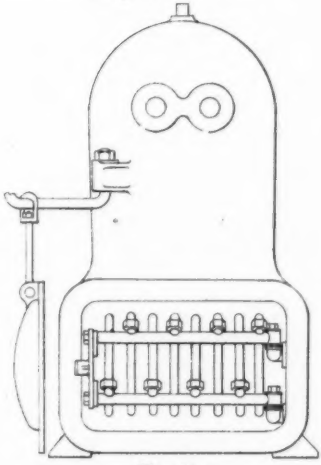

Fig. 11 b.

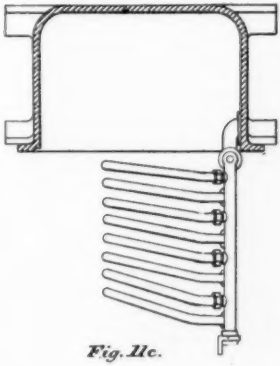

Fig. 11c.

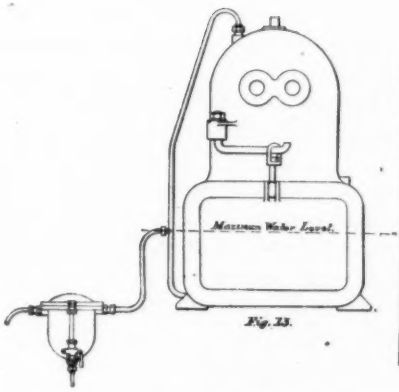

Fig. 13.

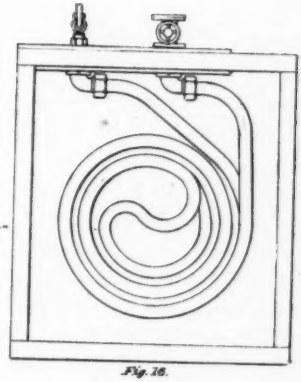

Fig. 16.

Fig. 17.

Should it be desired to replace a dirty set of tubes with a clean set, two nuts are removed from the plugs, and the inlet and outlet tubes with all the attached coils are lifted off, and the spare set lifted on. There are no flat-sided steam chests or jointed tube plates in this arrangement, all the parts subjected to boiler pressure being tubular, of brass and copper. Testing is also an easy operation, as by opening the steam valve and closing the drain the entire heating surface can be examined, and all the joints being in front are easily accessible for adjustment. In evaporators of large size the heating surface is divided into two sets, each set being independently mounted on the steam hinges or trunnions; the object of the arrangement being that each set of coils can be lifted by one man without the aid of any mechanical appliance.

In all the foregoing evaporators the contained water is simply boiled, but in the Yaryan apparatus the water is delivered in a fine spray through a series of tubes in direct connection with the condenser, and the resulting brine falling into a receiver is withdrawn by a special pump. An evaporator being simply a boiler, the mountings are very similar. Fig. 12, shows a special bye-pass drain cock which admits of continuous brining by an independent adjustment, which is not affected by the complete periodical blowing of the entire contents. Some makers allow the sea water to enter by gravity through a controlling float tank at the inlet, whilst others use a feed pump driven by the air pump lever. The writer favors the latter plan, as it renders the position of the evaporator in the ship independent of the sea level which, in shallow boats especially, is a distinct advantage. An evaporator naturally requires a little supervision, and is consequently usually placed in a position on the lower platform, readily accessible by the engineers. In the event of it being placed in some out-of-the-way position, and with a view of controlling the level from the starting platform, the arrangement shown in Fig. 13 may be adopted. This regulating device comprises a pipe connected at its lower end with the lower part of the evaporating vessel, where the brine is densest, and, at its upper end, with the steam space; at the desired water level, a

branch pipe is taken to a float tank which may be situated at any distance from and below the evaporator.

In these times of severe competition, when every detail on shipboard is viewed from a commercial standpoint, the probable cost of obtaining fresh water by means of an evaporator is a most important consideration. There are several arrangements available; as steam may be taken from the boiler direct, or from the receiver after having done work in the engine, and the steam generated in the evaporator may either be led to the condenser or to the hot well. In order to compare the relative economy of these methods, loss by radiation may be neglected as it is practically a constant quantity; also, for the sake of simplicity, the usual tables on the properties of steam may be taken as applicable to the general conditions.

STEAM SUPPLIED TO THE EVAPORATOR FROM BOILER, AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO HOT WELL.

In considering the method by which steam is supplied to the evaporator direct from the boiler, and the steam generated in the evaporator is condensed amongst the feed water in the hot well or its equivalent, let it be assumed that the pressure in the evaporator is one pound per square inch and that the water fed to the evaporator is taking from the circulating pump discharge at a temperature of 80° F. Experience has shown that evaporators at sea should be worked at a density of from $\frac{3}{32}$ to $\frac{4}{32}$, but for purposes of calculation let us assume $\frac{3}{32}$, and in order to maintain that density in the evaporator one-third of the total amount of water fed to the evaporator must be discharged into the bilge or overboard, consequently to produce one pound of pure steam $1\frac{1}{2}$ pounds of sea water must be supplied to the evaporator, of which 1 pound is evaporated in steam and $\frac{1}{2}$ pound is discharged as hot brine; therefore the total heat required to make 1 pound of pure steam is the sum of the heat in the steam and that in the discharged brine.

The temperature of steam at 16 pounds abs. = 216.3° F.

The heat in 1 pound of steam at a temperature of 216.3 from water at 80° F..... 1099.4 T.U.

The heat in ½ pound of brine at a temperature of 216.3 from water at 80° F..... 68.1 T.U.

Therefore the total heat required to produce 1 pound of pure steam ..... 1099.4 + 68.1 = 1167.5 T.U.

As the generated steam is passed direct to the hot well and is entirely condensed amongst the feed water it gives up the whole of its heat, so the net cost of producing 1 pound of steam is (1167.5 — 1099.4) = 68.1 T.U., or, in other words, the actual expenditure of heat is that due to brining.

STEAM FROM BOILERS, GENERATED STEAM TO HOT WELL.

Received by evaporator.	Thermal units.	Discharged by evaporator.	Thermal units.
Heat required to produce one pound of steam at a temperature of 216.3 above 80	1,167.5	Heat given up to hot well..	1,099 4
		Balance in brine.....	68 1
Total.....	1,167.5	Total.....	1,167.5

The heat value of 1 pound of good coal may be taken at 14,500 T.U., and by assuming the boiler efficiency to be 66.7 per cent., which was the average result obtained on the trials of the Research Committee of the Institute of Mechanical Engineers, we have $\frac{14,500 \times .666}{966.6} = 10$ pounds of water evaporated from and at 212° F. per pound of coal, so that 9,666 T.U. will be obtained from the combustion of 1 pound of coal, and the amount of pure steam generated by 1 pound of coal with this arrangement will be $\frac{9,666}{68.1} = 141.9$ pounds, or the amount of coal required to make 1 ton of pure steam $\frac{2,240}{141.9} = 15.7$ pounds.

STEAM SUPPLIED TO EVAPORATOR FROM BOILER, AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO THE RECEIVER OF THE LOW PRESSURE ENGINE.

In this case the generated steam from the evaporator is discharged into the low pressure casing and does work upon the low pressure piston before it is condensed. Again availing ourselves of the data contained in the report of the committee

already referred to, we find that in economical triple expansion engines about 17 per cent. of the total heat in the steam is converted into work; for the sake of simplicity, however, consider the efficiency as 18 per cent., and assuming that the power developed in each cylinder is equal, one third of this, or 6 per cent. of the total heat is utilized in each cylinder; it therefore follows that 82 per cent. of the heat is rejected, that the amount of heat entering the low pressure casing is 88 per cent. of the total supplied to the engine, and, of the total heat supplied to the low pressure cylinder, $\frac{6 \times 100}{88} = 6.82$ per cent. is converted.

Let the pressure in the low pressure casing be 7 pounds per square inch and the temperature of the evaporator feed be 80° F., as in the previous case.

Temperature of steam at 22 pounds abs. = 233.1° F.

Heat in 1 pound of steam at a temperature of 233.1° F. from water at 80° F..... 1,104.5 T.U.

Heat in $\frac{1}{2}$ pound of brine at a temperature of 233.1° F. from water at 80° F..... 76.5 T.U.

Heat required to produce 1 pound of pure steam = (1,104.5 + 76.5) = 1,181 T.U.

The equivalent weight of steam if taken from the boiler at 160 pounds pressure and discharged from the evaporator coils at a pressure of 60 pounds abs. or 292.7° F. would be:—

The temperature of steam at 175 abs. = 370.8° F.

Heat in 1 pound of steam at 370.8 above 292.5 = 933.7 T.U.

To produce 1 pound of steam in the evaporator $\frac{1,181}{933.7} = 1.26$ pounds must be taken from the boiler.

Assuming that this steam had passed through the engine in the ordinary manner, and taking the temperature of the hot well at 120° F., the heat in 1 pound of steam at 370.8° F. above 120° F. = 1,106 T.U., so that if instead of being taken to the evaporator it had passed through the engine in the ordinary manner, the amount converted into work would have been $1,106 \times 1.26 \times .18 = 251$ T.U., and of the heat passed from the evaporator to the low pressure, $1,104.5 \times .0682 = 75.3$ are converted into work, or $\frac{75.3 \times .100}{251} = 30$ per cent. of the total useful heat had it

passed through the whole engine; therefore the available useful heat given off by the evaporator is $1{,}104.5 \times .30 = 331.3$ T.U. To this must be added the heat which is contained in the drain from the coils and which is led to the hot well, viz., $(292.7 - 120) \times 1.26 = 217.6$ T.U.

STEAM FROM BOILERS, GENERATED STEAM TO LOW PRESSURE CASING.

Received by evaporator.	Thermal units.	Discharged by evaporator.	Thermal units.
Heat in 1.26 pound of steam at a temperature of 370 8° F: above 120° F., 1,106.4 × 1.26	1,394	Equivalent value of heat utilized in low-pressure cylinder	331.3
		Heat carried forward to the hot well from coils	217 6
		Balance unaccounted for	845.1
Total	1,394	Total	1,394

The net cost of producing 1 pound of pure steam is, therefore, the balance as above, and the amount of pure steam generated per pound of coal $= \frac{9,666}{845.1} = 11.43$ pounds; consequently the amount of coal required to produce 1 ton of fresh water $= \frac{2,240}{11.43} = 196$ pounds.

STEAM SUPPLIED TO EVAPORATOR FROM INTERMEDIATE PRESSURE RECEIVER AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO HOT WELL.

In this arrangement, steam is taken from the intermediate pressure casing (after having done work in the high pressure cylinder) and employed in the evaporator to produce steam at a pressure of 1 pound above the atmosphere, the evaporator steam being taken direct to the hot well and there condensed amongst the feed water. Let the data in this case be as follows:—steam in the intermediate pressure casing at 50 pounds pressure, temperature of evaporator feed 80° F., and temperature of the hot well 120° F. The heat required to produce 1 pound of pure steam will be the same as in the first example, viz., 1,167.5 T.U. Let the temperature of the discharge from the coils be that due

to a pressure of 15 pounds per square inch or (say) 30 pounds abs. = 250.4° F. Temperature of steam at 65 pounds abs. = 298° F.

Heat in 1 pound of steam at a temperature of 298° F. above water at 250.4° F. = 953.9 T.U.

Therefore, to produce 1 pound of pure steam in the evaporator $\frac{1,167.5}{953.9} = 1.22$ pounds of steam must be taken from the intermediate pressure casing. This, on the basis explained in the second arrangement, is equivalent to $1.22 \times \frac{100}{94} = 1.3$ pounds of boiler steam, the total heat per pound of water at 120° F. being 1,106.4 T.U. If, therefore, the heat contained in 1.3 pounds of steam had passed through all the cylinders, 18 per cent. would have been converted into work, 6 per cent. or one-third of the effective heat being utilized in the high pressure cylinder; the equivalent of the total heat is therefore $1,106.4 \times 1.3 \times \frac{1}{3} =$ 479.4 T.U., which represents available useful heat discharged from the evaporator.

There is also the heat in the condensed steam from the coil or (250.4 — 120) 1.22 = 159 T.U.; and lastly, the steam formed in the evaporator being taken to the hot well and there condensed, it gives up the whole of its heat above 120° = 1,059.4 T.U.

STEAM FROM INTERMEDIATE PRESSURE CASING, GENERATED STEAM TO HOT WELL.

Received by evaporator.	Thermal units.	Discharged by evaporator.	Thermal units.
Heat in 1.3 pounds of steam at a temperature of 370 8° F. above 120° F., 1,106.4 × 1.3	1,438.3	Equivalent value of heat utilized in high pressure cylinder	479.4
Surplus heat after allowing for heat in the brine	259.5	Heat carried forward to hot well from coils	159
		Heat given up by generated steam to hot well	1,059.4
Total	1,697.8	Total	1,697.8

From the above statement it will be seen that there is a reserve of 259.5 T.U. beyond the expenditure of heat in brining. Expressing this in coal, as before, the equivalent is 1 pound of

coal for the evaporation of $\frac{9,666}{259.5} = 37.2$ pounds of pure steam; therefore, in producing 1 ton of fresh water, by employing an evaporator in this manner, there is a reserve balance in favor of the evaporator equal to $\frac{2,240}{37.2} = 60.2$ pounds of coal. This theoretical result is based on perfect adiabaticity, and is greater than that which would be obtained in practice, as a large amount of heat naturally disappears by initial condensation.

STEAM SUPPLIED TO EVAPORATOR FROM BOILER, AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO CONDENSER.

In this arrangement it is customary to place a vapor or reducing valve between the evaporator and the condenser; the evaporation will therefore take place at about atmospheric pressure, the feed being at 80° F., as before.

Temperature of steam at atmospheric pressure 212° F.

Heat of 1 pound of steam at 212° F. above water at 80° F. = 1,098.1 T.U.

Heat in $\frac{1}{2}$ pound of brine at 212° F. above water at 80° F. = 66 T.U.

Heat required to produce 1 pound of pure steam 1,098.1 + 66 = 1,164.1 T.U.

As the steam generated in the evaporator is taken to the condenser and there condensed, it forms 1 pound of pure water at the hot well temperature of 120° F., the total heat above 120° F. carried away in the circulating pump discharge at 80° F. being 1,058.1; or 1,098.1 — 1,058.1 = 40 T.U., which represents the amount of useful heat sent to the hot well.

STEAM FROM BOILER GENERATED STEAM TO HOT WELL.

Received by evaporator.	Thermal units.	Discharged by evaporator.	Thermal units.
Heat required to produce 1 pound of steam at a temperature of 212° F. above 80° F.	1,164.1	Heat given up by 1 pound of steam in condenser...	40.
		Balance of heat lost in circulating water.....	1,124.1
Total.....	1,164.1	Total.....	1,164.1

The net cost of producing 1 pound of steam is, therefore, 1,124.1 T.U., whilst the combustion of 1 pound of coal would produce $\frac{9,666}{1,124.1} = 8.6$ pounds, and 1 ton of fresh water would require $\frac{2,240}{8.6} = 260$ pounds of coal.

These investigations show that water may be obtained from an evaporator for a nominal expenditure of coal, or very wastefully, depending entirely on the arrangements adopted. The steam supply from the intermediate pressure casing is more economical from a heat expenditure point of view than a direct connection to the boiler, but there are practical considerations in favor of the latter which will be referred to later. With reference to the steam generated in the evaporator, there is no doubt whatever that discharging direct to the condenser, although a cheap method as regards the cost of fitting up the apparatus on board, is distinctly the most uneconomical which could be adopted, and although a connection to the condenser is sometimes convenient in port, yet at sea it should never be used, as it is simply equivalent to wilfully throwing coals overboard. There is in the hot well a medium, viz., the feed water, which will readily absorb all the heat contained in the steam generated by the evaporator, and in such a manner that none of the heat so absorbed is wasted; consequently, to adopt any other method is sacrificing possible economy.

The condensing of the steam amongst the feed water naturally raises the temperature of the latter, but not to such a point as will influence the working of the feed pumps unless the design is very faulty. If any difficulty occurs, a remedy is often found by making a connection by a $\frac{3}{8}$-inch pipe between the top of the feed pump barrel and the condenser. In order to overcome certain objections to evaporating direct into the hot well, the writer has adopted an independent vessel, Fig. 19, which has given good results in practice. The vessel contains two chambers, one of which forms a receiver or well for the feed water on its passage from the hot well to the pumps. Projecting into this well is a nozzle with radial openings through which the steam from the evaporator flows, and by giving the water a centrifugal motion is rapidly condensed; any freed air escapes

by an exit pipe, and the heated water overflowing from the receiver is drawn through the suction valve of the feed pump in the usual manner.

The effect of an accumulation of scale in boilers does not come within the scope of this paper, but, considered briefly, the results are:

(1.) Decreased efficiency of the heating surface, causing an unnecessary expenditure of fuel.

(2.) Increased temperatures of the materials forming the heating surfaces, causing collapse or deformation of furnaces and leakage of tubes and joints.

(3.) Increased wear and tear of boilers.

(4.) Excessive boiler cleaning expenses.

The rapid increase in the temperature of the furnace plates, when covered with but a slight coating of scale (especially when it contains oil) is not always fully appreciated until accidents happen, and for this reason a feed water filter is a valuable adjunct to an evaporator. Some very interesting investigations on boiler deposits have been made by Mr. Isaac, the consulting engineer for the Eastern Telegraph Company, who has given the subject careful study on account of the nature of the work of cable laying necessitating boilers being kept under steam for long periods. In one boat, after 110 days steaming, the boiler on being opened out was found perfectly clean and only required the light powder with which the surfaces were covered brushing down and washing out. In another boat, after 103 days steaming, a similar result was obtained. Each boat was fitted with an evaporator and an Edmiston filter, the boilers, of 160 pounds pressure, being worked under Howden's forced draft, and in both cases zinc and soda were used. If boilers were treated in this manner, maximum efficiency would be maintained, the expenditure of fuel, the cost of boiler up-keep and the expenses in scaling and cleaning being reduced to a minimum. An example recently came under the writer's notice, in which a boat brought all her furnaces down, yet the thickness of scale on the heating surfaces was by no means excessive. Subsequent analysis of the deposit gave the following extraordinary result:

Gritty matter and sand	2.69 per cent.
Oxide of copper	1.07 "
" zinc	3.42 "
" iron	24.21 "
" magnesium	16.52 "
" calcium	2 02 "
Oily matter of acid character, combined with oxides of copper, zinc, iron and magnesium	32.02 "
Oil in its natural state, but mechanically mixed through the deposit,	17.98 "
Total	99 93 per cent.

This remarkable deposit contains, therefore, 50 per cent. of oil. The oil on being examined was found to have a vaporizing point of 305 degrees F., and was, therefore, altogether unsuitable for the internal lubrication of high pressure engines.

The efficiency of the heating surface in an evaporator depends chiefly on the steam pressure within the tubes and the thickness of scale on the tubes. With a view of ascertaining the effect of scale, the following experiments were made. Fig. 14 is a vessel open at the top, within which are fitted ordinary condenser tubes terminating at each end in chambers for the inlet steam and outlet water of condensation, the latter being conveyed to a drainer so that full pressure could be maintained within the tubes. Dry steam was supplied to the tubes at a pressure of 45 pounds per square inch, the water to be evaporated taken from the sea, and a density maintained of about $\frac{3}{32}$ to $\frac{4}{32}$ by continuous brining. As the intention was to ascertain the decrease in efficiency due to the formation of scale on a clean tube, every precaution was taken to maintain constant conditions in order that no scale might be cracked off by any variation in temperature.

The trial lasted 48 hours, all water being carefully measured and every provision made for obtaining accuracy. Fig. 15 gives the results; from which it is seen that the evaporation during the first hour was 32 gallons, falling rapidly to $8\frac{1}{2}$ for the twelfth hour, and continuing to decline gradually to 4 gallons for the forty-eighth hour. The initial drop being very rapid, it was suggested that water in suspension passed off with the steam; half the tubes were then taken out and the experiment repeated with

FIG. 15.

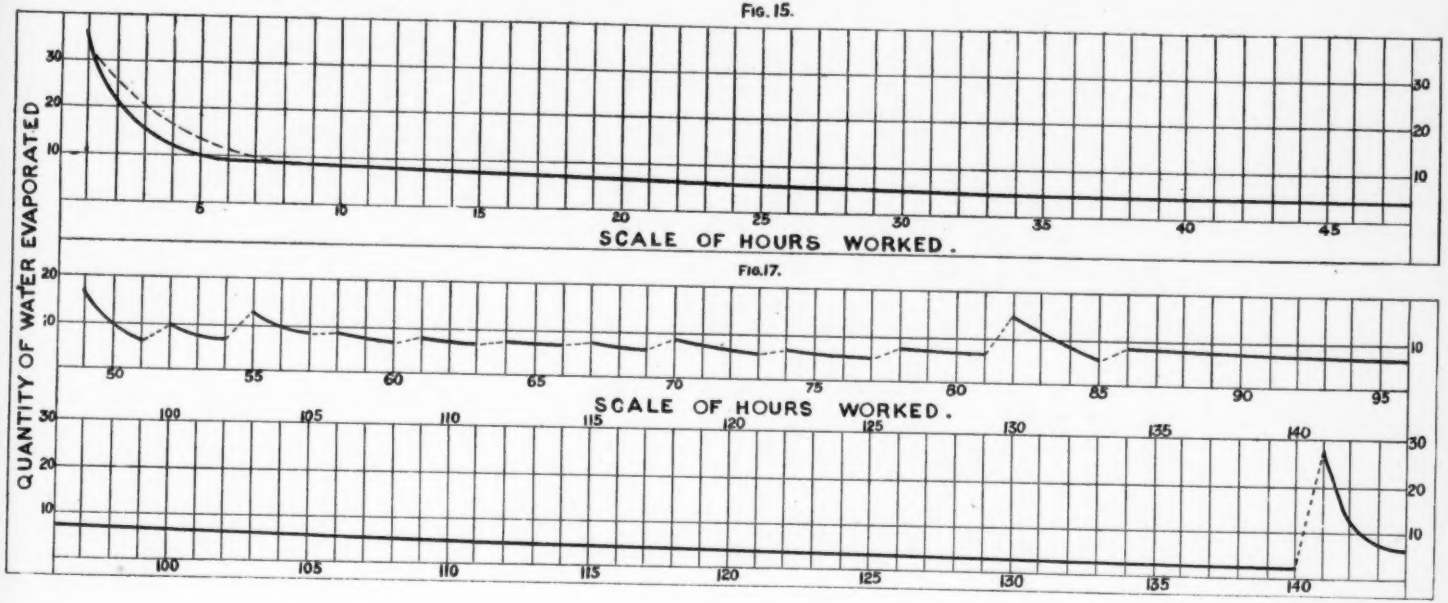
QUANTITY OF WATER EVAPORATED
30
20
10
5
10
15
20
25
30
35
40
45
SCALE OF HOURS WORKED.

FIG. 17.

20
10
50
55
60
65
70
75
80
85
90
95
SCALE OF HOURS WORKED.
30
20
10
100
105
110
115
120
125
130
135
140

practically identical comparative results. At the end of the trial, the scale was about $\frac{1}{32}$ inch thick.

Fig. 16 illustrates another vessel, in which the heating surface is in the form of volute coils and with which the same experiment was made with exactly similiar results. The pressure within the coils and the temperature of the water outside being kept constant, there was no tendency for the scale to crack off, and at the end of the trial the coils were covered uniformly with scale $\frac{1}{32}$ inch thick.

It will be noticed that the curves are different on Fig. 15 for the first few hours in the two experiments, this being due to the fact that the first vessel had a larger amount of contained water than the second, therefore the density of the latter rose more rapidly and scale formed more quickly. At the end of the forty-eighth hour steam was shut off, and after the water became cold it was drained away. Sea water was then admitted, and on steam being turned full on a large amount of scale could be seen to crack off and fall to the bottom of the vessel. The effect of this is clearly shown on the diagram, Fig. 17, as, although the evaporation had fallen to four gallons during the forty-eighth hour, yet, after the coils had been subjected to this treatment, the evaporation rose at once to 17.

After three hours working the water was again drained away, sea water admitted, steam turned on and scale thereby cracked off, this process being repeated at intervals until the eighty-first hour, with the result that, although the evaporation had fallen to four gallons during the forty-eighth hour of the continuous trial, yet, after a further thirty-three hours of intermittent working, it had risen to six, which corresponds to the evaporation at the twentieth hour of the continuous trial. At the end of the eighty-first hour the evaporator was blown down, cold water admitted, steam turned on for a few minutes, and then the whole of the water was drained off a second time. The result of this is seen at once in the diagram, Fig. 17, where it will be noticed the evaporation for the eighty-second hour has risen to $15\frac{1}{2}$ gallons.

At the end of the eighty-fifth hour a continuous trial of fifty-

five hours duration was made *without* brining in any way, and at the end of that time, that is, for the one-hundred and fortieth hour, the evaporation had fallen to two gallons. On opening the evaporator it was found that a large quantity of salt had been deposited, and that underneath the salt crystals the coils were coated with scale $\frac{1}{16}$ inch thick.

The above method of filling with cold water, admitting steam and draining off, was repeated, and a large portion of the scale cracked off, after which the apparatus was closed up and the experiment continued for a further four hours, with the result that during the first hour the evaporation was 29 gallons, falling to 7 for the fourth hour. The total time therefore, that this trial lasted was 144 hours, and during the whole of this time the coils were not scaled by any mechanical means, the process of blowing down periodically being the only method adopted of maintaining the efficiency of the apparatus.

How long the efficiency could be maintained with this method of working the experiments do not show, but the natural inference is that the decrease in efficiency would be slow, especially if a greater pressure of steam was available; ultimately, however, it would be necessary to scale the tubes by mechanical means. It is for this reason that the writer advocates connecting an evaporator direct to the boiler, as not only is the maximum pressure of benefit if the coils are allowed to become heavily coated with scale, but there is also the advantage of the greater expansion and movement of the coils due to the sudden application of the full pressure, thereby materially increasing the tendency for the scale to crack off.

A double connection to the boiler and intermediate pressure casing is of course the more complete arrangement, as the economy due to the use of receiver steam may be obtained when the evaporator is of ample size, and in fair working condition; whilst if the coils are dirty, or an extra amount of water is required, boiler steam is available.

Repeated instances have come under the writer's notice of where the coils have been encased in a solid block of salt or covered with a scale of exceptional hardness. Both these results

are due to the careless working and insufficient attention to brining. It is necessary for success that the density should be maintained from $\frac{3}{32}$ to $\frac{4}{32}$, as if allowed to become too dense, salt will be rapidly deposited on the coils, whilst if the density is kept too low by excessive brining, not only is there a large amount of heat in the discharged water, but the scale formed on the tubes is very hard and difficult to remove. On account of the density of the water and the low pressure of evaporation, there is sometimes a slight tendency to prime, and for this reason a portion of the heating surface is usually kept above the water level in order to break up the bubbles and so prevent water, in the form of spray, passing off with the steam.

A connection to the condenser is very convenient after blowing down, as the vacuum enables the evaporator to be filled from the sea more rapidly when this is being done. Care should be taken to fully immerse the whole of the tubes before turning on steam, the excess water being drained away as soon as the cracking off process is completed. The detached scale should also be cleaned out frequently, as when present in suspension it increases the tendency to prime.

Evaporators are sometimes used as condensers for winches when in port, and certainly seem well adapted for the purpose. The cooling surface required is usually in excess of what is necessary for evaporating purposes, consequently an increased size of evaporator has to be fitted. In order to minimize this increase in size, the writer has designed a combined apparatus, as in Fig. 18, the feature of which is the utilization of the steam space of an evaporator for the reception of a set of condensing coils, such set being a duplicate of the set of evaporating coils in the lower part of the vessel for which they are available when required. In the illustration the coils are divided into three similar sets. When evaporating, two sets are in use and one set available as spare; when condensing, this spare set is fixed in the steam space so that the available surface when used as a condenser is 33 per cent. greater than the surface when used as an evaporator. This extra surface in the steam space is also of value when it is desired to work the evaporator at its maximum,

as it vaporizes any water which may be in the steam due to violent ebullition, and would, therefore, be well adapted for warships or torpedo boats where reduction of weight is a great desideratum. On passenger and better class boats, winch condensers or exhaust tanks are a necessity, in order to overcome the delay and inconvenience caused by the escaping steam; but it is the donkey boilers which reap the great benefit, as, in cargo boats especially, they never have a large margin in size, and being fed direct from the sea, thereby causing an ever increasing accumulation of scale, they constitute not the least of the worries on board a steamship. The question of first cost has been the obstacle, however; but now that evaporators are an established necessity, it seems but a natural development that they should, with a little extra outlay, be rendered available for condensing purposes, and so materially add to the general efficiency. The writer had hoped to include the results of experiments with this apparatus, but as they are incomplete he will have pleasure in communicating them to the Institution at a later date.

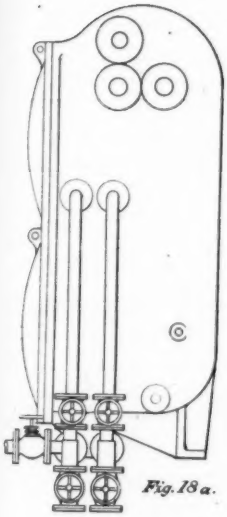

Fig. 18a.

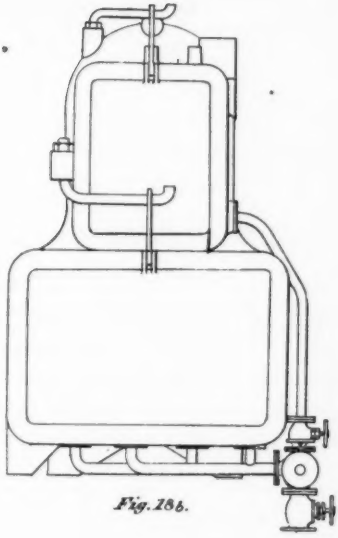

Fig. 18b.

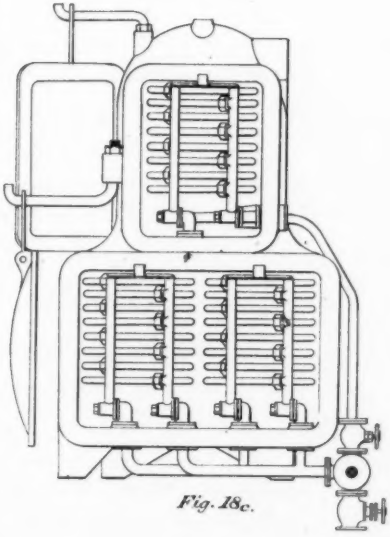

Fig. 18c.

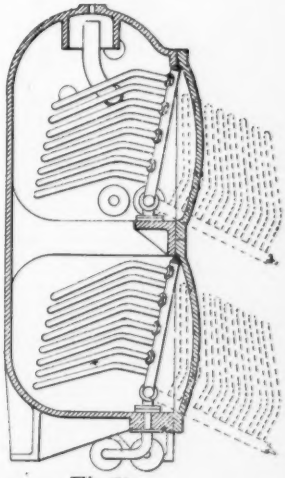

Fig. 18d.

CURVES SHOWING THE RELATION BETWEEN EQUIVALENT HOLLOW AND SOLID SHAFTS.

By Professor W. F. Durand, Cornell University.

The general advantages of hollow, as compared with solid shafts may be considered as two in number.

(1.) The greater assurance of soundness and reliability of metal arising from the possibility of inspection on both its inner and outer surfaces, coupled with the removal of the inner core as the part most likely to contain flaws and imperfections.

(2.) The saving of weight for equal strength.

Equivalent shafts are assumed as those which will carry equal turning or bending moments with equal outer fiber stresses.

By the well known methods of mechanics, we have for the general value of the moment of the internal stresses developed by an external torsional moment,

$$M = \frac{\pi k (r_1^4 - r_0^4)}{2r_1}.$$

Where r_1 = outer radius,
and r_0 = radius of hole.

If $r_0 = 0$, and $r_1 = a$, we have for the solid shaft:

$$M = \frac{\pi k a^3}{2}.$$

Hence, equating, we have as the relation between a hollow shaft and the equivalent solid shaft:

$$r_1^4 - r_0^4 = r_1 a^3. \qquad (1)$$

By means of this equation we may deduce a graphical representation of the relation between the internal and external radii of a hollow shaft and the radius of the equivalent solid shaft. Empirical formulæ, or formulæ with empirical constants, are

usually arranged for solid shafts, so that in any practical problem we may usually find first the solid shaft which will fulfil the conditions imposed. This representation will then give a wide series of hollow shafts which shall be its equivalent.

In making the necessary computation for the plotting of the curves, it is found preferable to assume for a fixed value of r_1, a regular series of values of a, and thence to derive the resultant values of r_0. These operations being repeated for the range of radii to be included, the values are plotted as shown in the lower part of the diagram, and smooth curves are drawn through all points which, for each curve, give characteristics equivalent to one of the series of values of a.

In the diagram as actually plotted, diameters instead of radii are used.

It thus appears that any curve, as 12—12 fixes the outer and inner diameters for a series of shafts equivalent to a solid shaft 12 inches in diameter. Thus for example a shaft $12\frac{1}{2}$ inches outside diameter with a 7-inch hole is equivalent to a 12-inch solid shaft, and similarly for others.

In the matter of relative weight, it will be convenient to relate everything to the solid shaft as the basis of comparison.

The weight of the hollow shaft is proportional to $(r_1^2 - r_0^2)$, while that of the solid shaft is proportional to a^2, where r_1, r_0 and a have the relations determined above in (1). The ratio of the two weights will, therefore, be:

$$y = \frac{r_1^2 - r_0^2}{a^2}. \qquad (2)$$

Eliminating r_0 between (1) and (2), we have:

$$a^4y^2 - 2a^2r_1^2y + r_1a^3 = 0.$$

$$\text{Whence } r_1 = a\left(\frac{1}{4y} + \sqrt{\frac{y}{2} + \frac{1}{16y^2}}\right). \qquad (3)$$

We then give to y a value as .50 and find $r_1 = 1.207\ a$. Hence in the upper part of the figure we take all along the 50 per cent. line points given by 1.207 times the values of a, and similarly for $y = 60$ per cent., etc. After the points are thus laid off, they

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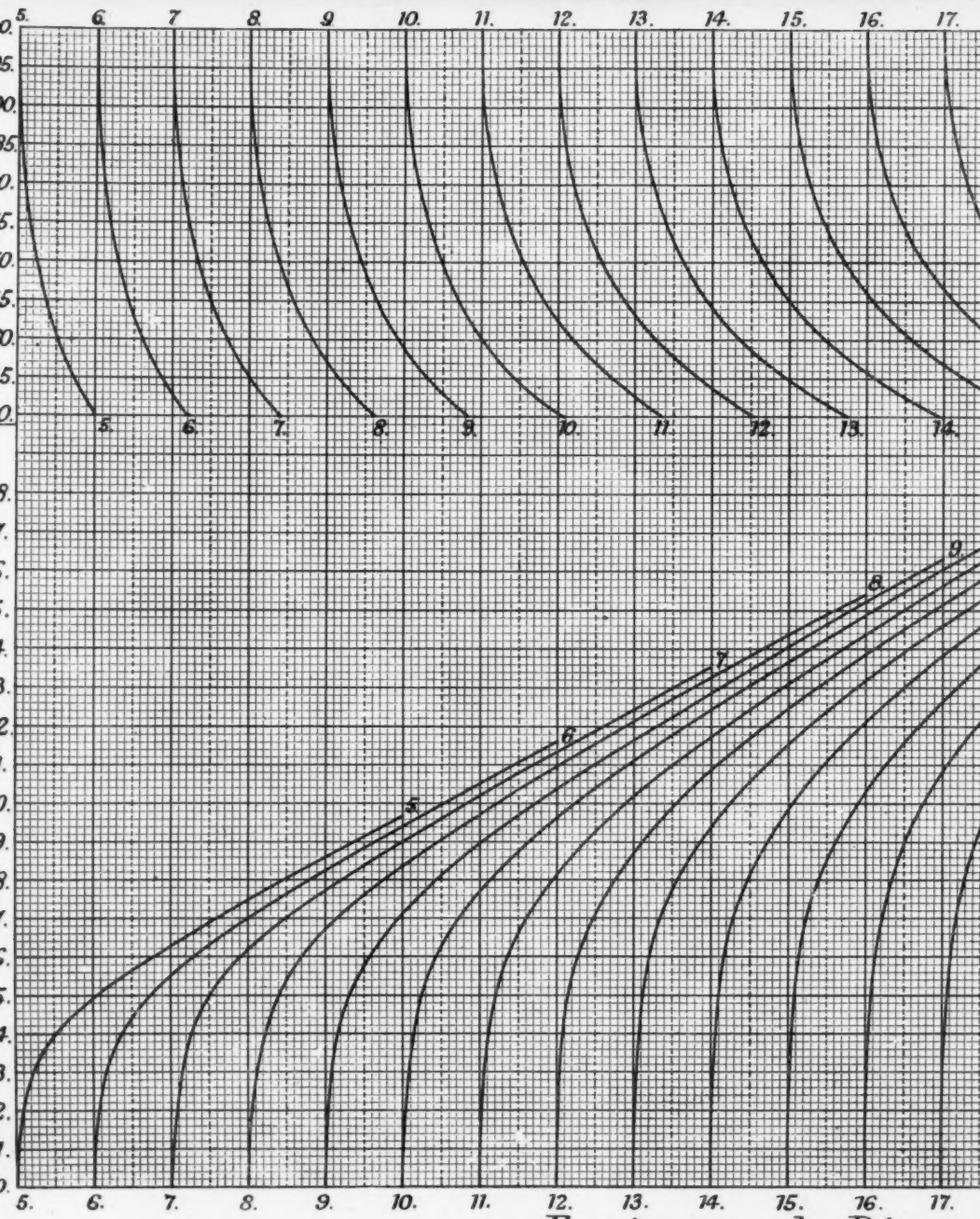
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5. 6. 7. 8. 9. 10. 11. 12. 13. 14.
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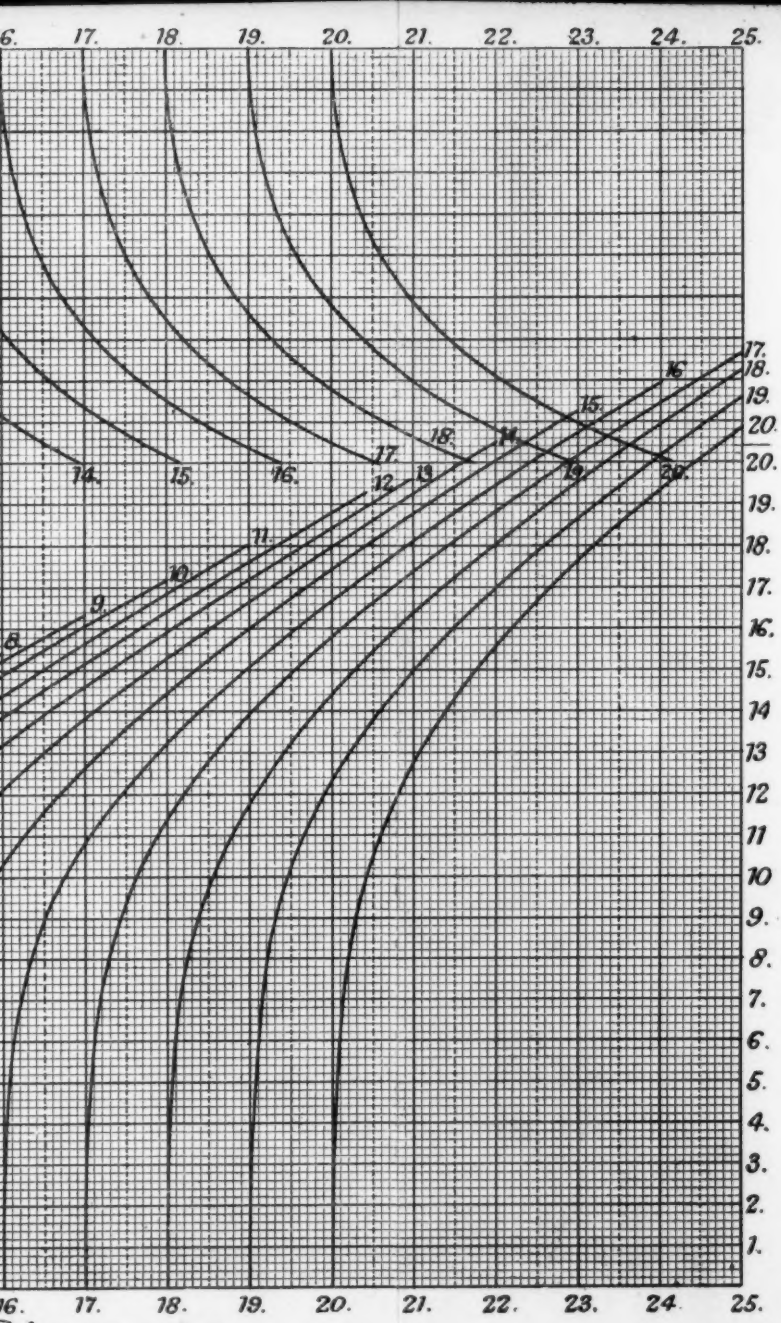
External Diam
All-Shafts given by any one Curve ar



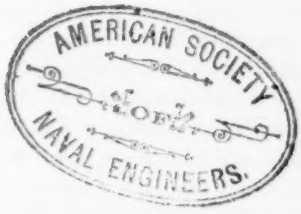
Diameter.

rve are equivalent.

are so joined as to unite in one curve all relating to the equivalents of the same solid shaft. Thus, the upper curve 12—12 relates simply to the equivalents of a 12-inch solid shaft.

The use of the upper curves is best illustrated by an example. Taking, as above, the $12\frac{1}{2}$-inch shaft with a 7-inch hole, we pass vertically upward from the corresponding point on the 12-inch curve until we meet the 12-inch curve in the upper series. The corresponding ordinate on the scale of per cent. is 71, showing that a hollow shaft of these dimensions, while the equivalent of the 12-inch solid shaft in strength, will have only 71 per cent. of its weight.

It is readily seen that the relation between hollow and solid shafts is the same for bending as for twisting moment, and that the condition for equivalence will be the same. These curves may, therefore, be used to determine equivalent dimensions relative to either form of stress.



TEST OF WOUND COPPER PIPES.

[Made at the Imperial Dockyard, Wilhelmshaven, Germany, and reported in the "Zeitschrift des Vereines Deutscher Ingenieure" by Chief Engineer Köhn non Jaski.]

TRANSLATED BY WM. WACHSMANN, ESQ., ASSOCIATE.

In the German Navy, steam pipes have always been made of copper, and the thickness calculated so that the stress on the material should not exceed 2,844 pounds per square inch, it being assumed that the thickness is uniform throughout and the material homogeneous. Experience has shown that drawn copper pipes can not be depended upon with certainty, whilst the strength of brazed pipes depends entirely on the quality of the brazing, and consequently on the skill of the coppersmith.

In the careless treatment of pipes in the fire, the material adjacent to the seam to be brazed will be burnt and the strength and ductility considerably reduced. In the German Navy, as elsewhere, experience with brazed pipes has been so bad that their use had to be very much restricted. It is only necessary to recall the pipe explosion on the S. S. *Elbe* of the Royal Mail Co., in 1887, in which it was subsequently proven by test pieces taken from next the brazed seam that the strength of the material had decreased 13 per cent., and tensile specimens taken from near the seam and some distance from it showed a loss in ductility of 70 per cent.

In solid drawn pipes, unsound places are found, in the shape of longitudinal flaws, which are formed during the process of drawing, or are due to impurities in the original ingot; and these defects are only discovered after the pipe has been subjected to a hydrostatic pressure, and generally to a very high one.

To allow for these defects, the thickness of copper pipes for use in the German Navy was formerly determined by the formula

$$t = \frac{pD}{5689} + 0.059,$$

in which

t = thickness in inches,
p = steam pressure in pounds per square inch,
D = inside diameter of pipe in inches,

notwithstanding the fact that, in a pipe designed according to the formula $t = \frac{pD}{5689}$ (the thickness being considered uniform throughout), there was already a factor of safety of 10 with a stress of only 2,844 pounds per square inch on the material.

Isolated cases of copper pipe explosions have, however, given rise to the use of a still higher factor of safety.

As early as 1890, Denny, of Dumbarton, applied bands of round steel to steam pipes, as shown in Fig. 1, in order to increase their strength for very high pressures. They were from 0.236 to 0.314 inch in diameter, and were heated to a red heat before being put on. This practice was brought about by the explosion on the *Elbe*, where nine men were killed, and also by that at the Central Station, Deptford, July 9, 1889. Similar devices were subsequently used by other engine builders, amongst them F. Schichau, of Elbing, in the Austrian torpedo depot ship *Pelican*, and in the new engines and boilers for the Austrian battleship *Tegetthoff*, while the winding of pipes with copper wire was introduced in the English Navy.

In the experiments herein described, the attempt was first made to determine the strength that could be relied upon in drawn copper pipes, after making due allowance for unequal thickness and slight defects in material. For this purpose, pipes provided with flanges were taken from store and tested to destruction by hydrostatic pressure. The results of these tests are given in Table I.

The fractures in tests 1 and 3 occurred in perfectly homogeneous material at c and a respectively; in test 2, in a small slag place at c, and in test 4 in an unsound place at c. The

fractures were from 3.9 to 12.9 inches long, and 0.27 to 1.18 inches wide. The thickness measured at the lines of rupture should not be compared with that measured at the ends before testing, for, notwithstanding the longitudinal contraction of the pipe owing to the enormous expansion, the thickness was materially reduced. The pipes were presumably ruptured at the thinnest places. The factor of safety in tests 1 and 3 was ample.

The variation in thickness would be fully covered by using the formula,

$$t = \frac{pD}{5689} + 0.059,$$

but only in case there were no unsound places.

How dangerous such defects in material may prove, can be seen in test 4. Here the factor of safety was only about 6, and such pipes would surely burst in case of extraordinary pressures, such as that caused by water hammer, and even at much lower pressure, depending on the size of the unsound place and the thickness of the sound metal remaining.

These tests, as well as explosions which have occurred in practice, emphasize the necessity of increasing the strength of the pipes. Further tests were, therefore, made to determine the efficiency of different kinds of winding.

A pipe of the same dimensions as that used in test 1 was taken and wound with steel wire rope, but in such a way that it alternated with an unwound portion for a distance of 7.87 inches. The data of this test are given in Table II.

A comparison of test 5 with test 1 shows that the safety of a pipe with alternate windings is increased, but that such winding offers no protection against explosion if a defect exists in the material between the windings. From which it follows that only complete windings should be used.

The next thing to determine was the size of the wire rope. The following was adopted as a standard: the stresses due to the steam pressure should be uniformly distributed upon the sides of the pipe and the winding, and a resistance against the winding of at least 2,134 pounds per square inch should be obtained.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.

In these tests, drawn copper pipes 7.87 and 11.81 inches inside diameter, and 0.295 and 0.413 inch thick respectively, were used. According to the formula $t = \frac{pD}{5689}$, these pipes were suitable for a working pressure of 213 pounds per square inch, and thus a factor of safety of at least 10 was adopted.

The hydrostatic pressure in tests 6 to 11 was only carried far enough to destroy the wire rope used in winding the pipe. The rope was simply coiled around the pipes, which were made to order in Berlin, by C. Heckmann. Twenty test pieces from strips cut from the ends, and in a direction at right angles to the axis, showed an average tensile strength of 31,106 pounds per square inch and an elongation of 25.2 per cent. in a length of 7.87 inches; and after annealing 30,537 pounds tensile strength and 35 per cent. elongation. Cold bending and forge tests gave satisfactory results; so the material of the pipes was of the best quality. The results of these tests, 6 to 11, are given in Table III.

According to the results of test 6, copper wire rope proved too ductile. In spite of the great weight and cost of this kind of winding, the sides of the pipe were not much relieved, and the pipe was much expanded.

Galvanized steel wire rope of 0.1968 inch circumference proved too weak for pipes of 7.87 inches diameter, and steel wire rope of 0.492 inch and 0.7874 inch circumference, used for the 7.87 and the 11.81-inch pipe, was too heavy. The conditions laid down were fulfilled by using galvanized steel wire rope of 0.2952 inch circumference for the 7.87 inch, and 0.3937 inch circumference for the 11.81-inch pipes.

It now remained to determine the best method of winding. Accordingly, the various windings shown in Figs. 2 to 6 were used, and the pipes subjected to a hydrostatic pressure. As a matter of fact, the bights in the different windings were close together, as shown in Fig. 2; in the other figures, they are shown separated in order to make the method of winding clearer. The small figures indicate the direction of winding. Galvanized steel wire rope was used for all windings, except that of test 21, where

copper was again used, the reason for which will be explained further on.

After the breaking of the first bight in Fig. 2, the adjacent parts of the same winding were held in place by the other rope, wound in the opposite direction. But as soon as a bight of this second rope broke near the first place, all bights for a distance of 3.9 to 4.7 inches either side of it became loose.

In the winding shown in Fig. 3, the rope was very unfavorably strained, due to the knotting. Though the rope selected was heavier than would have been necessary according to test 10, nevertheless eight adjacent bights broke at a pressure of 1,877 pounds per square inch.

The winding shown in Fig. 4 gave better results. After the breaking of the first bight, the adjacent ones became loose, but after the pipe had expanded a little more, they again became tight.

The winding shown in Fig. 5 acted about the same as that shown in Fig. 4, except that the bights next the place of fracture became looser.

In the winding shown in Fig. 6, the first bight broke at a pressure of 2,418 pounds per square inch, the adjacent bights remaining perfectly tight. After increasing the pressure to 2,560 pounds, other bights broke, but all adjacent ones remained tight. Where the rope broke, the pipe expanded, and a number of other bights broke at a pressure of 1,422 and 1,707 pounds, but all bights which were not broken remained tight around the pipe. In test 17, with the same kind of winding, being a parallel test to 8, the first bight broke at 2,707 pounds. The pressure was then increased to 2,958 pounds, when other bights broke. The behavior of the bights was the same as in the preceding test.

Accordingly, the method of winding shown in Fig. 6 proved to be the most satisfactory, and from its behavior could be designated as thoroughly reliable for use on ship-board.

Tests 18 and 19 were then made with pipes having the same diameter, but less thickness, to determine the influence of these factors on the durability of the winding. As the results show, the expansion of the pipe, with the same internal pressure, was

much greater than in the case of pipes of greater thickness, and the steel wire rope broke much sooner. Therefore, to obtain the same safety in case of thinner pipes, the wire rope should be heavier.

As the specimens of pipes tested apparently showed no defects in the material, it remained to determine how a defective copper pipe would behave when wound with wire rope in the most favorable manner and subjected to a high pressure. To obtain this information, a pipe of the same dimensions as that used in test 17 was milled down to about three-fourths its original thickness for a distance of about 7.87 inches, and then wound as in test 17. At a pressure of 2,987 pounds (test 20) the first bight broke at the end farthest from the place where the pipe was weakened. In continuing the test, the pressure fluctuated between 2,133 and 2,347 pounds, while the part where the rope broke expanded and eventually broke at a pressure of 2,347 pounds in perfectly sound material. As the fracture did not take place at the weakest point, the locally decreased thickness had no influence on the strength of the wound pipe. The cause of this favorable result may be looked for in the small amount of yield in the steel wire rope, arresting the expansion of the pipe and thereby preventing the bursting at the weakened place. To verify this assumption, a parallel test, 21, was made with a copper wire rope winding, which had proved to be very yielding in test 6. At a pressure of 1,707 pounds the pipe burst at the weakened place for a distance of about 5 inches without breaking the copper wire rope.

Taking 213 pounds per square inch as the standard internal pressure for the tested pipe, the factor of safety in test 21 would be 8, while in test 20 it was 11, and the gain can only be attributed to the winding with the strong unyielding steel wire, which made the artificially created defect in the material harmless, while the copper wire increased the strength (compare with test 4) but not by any means in the same measure as the steel wire.

As a result of these tests, the following rules were promulgated in the German Navy for the design of copper pipes:

1. The stress in the material of copper pipes must in no case

exceed 2,844 pounds per square inch. In pipes which are wound according to the rules with steel wire rope, the strength due to winding must be eliminated from the calculation. Thickness of such pipes must be at least $t = \frac{pD}{5689}$ inch, and it must never be less than 0.157 inch, so that the flanges can be properly secured. Pipes which are not wound should have a thickness of at least

$$t = \frac{pD}{5689} + 0.059 \text{ inch.}$$

2. Brazed pipes are to be avoided for high pressures, and pipes for such pressures are to be either solid drawn or made of sheet copper with double butt straps and riveted.

3. When drawn pipes of a diameter of 4.72 inches and over are used for steam pressures of 100 pounds and over, they are to be covered with steel wire rope of the following dimensions, and wound in the manner shown in Fig. 6.

Inside diameter of pipe.	Circumference of steel wire rope.
inches.	*inch.*
4.72 to 5.9	0.2952
6.10 to 7.87	0.3937
8.07 to 9.84	0.492
10.03 to 11.81	0.5906
12.00 to 13.77	0.6889
13.97 to 15.74	0.7874

To protect the steel wire rope from corrosion, it must be covered with varnish before being wound around the pipe.

For the sake of completeness, the following rule may be added to which the results of other tests, to be published later, have led.

4. In all main steam pipes of 4.72 inches inside diameter and over, which are to carry a steam pressure of 100 pounds and over, the flanges are to be riveted on, not brazed.

For those who think that the safety required in the foregoing rules is too high, it may be remarked that tests were made at the dockyard in Wilhelmshaven with pipes 5.9 and 12.2 inches diameter, the thickness being respectively 0.19685 and 0.23622

inch. They were partly filled with water so that artificial water hammer might be produced, and steam of 71 pounds pressure admitted, when rupture of the pipe occurred in a similar manner to that which occurs on board ship, and which is usually attributed to water hammer. A pressure as high as 2,133 pounds per square inch was registered on a maximum pressure gauge. These tests were described in the Marine Rundschau, March, 1894.

The increased weight and cost of steam pipes due to winding with galvanized steel wire rope is entirely justifiable, and will have to be accepted until some other mode of manufacture, or other materials which can be used on ship-board, permit such safeguards to be dispensed with.

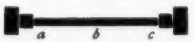
Tests made at the imperial dockyards with copper pipes made according to the Mannesmann and the Elmore processes have not come up to expectations.

TABLE I.

No. of test.	Inside diameter.	Thickness.	Length before test.	Working pressure according to *	Expansion of pipe. At pressure of	Expansion of pipe. A.	Expansion of pipe. B.	Expansion of pipe. C.	Length after test.	Internal pressure when rupture occurred.	Thickness at point of rupture.	Factor of safety.
	Inches.	*Inches.*	*Inches.*	*Lbs. sq. in.*	*Lbs. sq. in.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Lbs. sq. in.*	*Inches.*	*Pounds.*
1	5.11	.2362	68 3083	196.279	853.39	.1181	.1181	.1574	68.15	2,389	.1574	11.4
					1,706	.2362	.1968	.2362				
					1,920	.3149	.2362	.3149				
					2,176	.5906	.5512	.5512				
					2,389	.8268	.7874	**.9843**				14.3
2	5.51	.1968	70 15	142.23	853.3	.1181	.1181	.1574	69.05	2,034	.1181	
					1,564.5	.3149	.3543	.3543				
					1,778	.3937	.4331	.5118				
					1,920	.5906	.6299	.7087				
					2,034	.8662	.9843	**1.378**				
3	9.05	.2756	45.98	136.54	341.3	.0393	.0393	.0393	45.27	1,479	.1771	10.8
					711	.1574	.1574	.1574				
					1,138	.5512	.5512	.5906				
					1,422.3	1.4173	1.338	1.338				
					1,479	**2.126**	1.732	1.653				
4	9.05	.2756	62.67	136.54	341.3	.0787	.0393	.0787	62.56	825	Unsound place.	6.0
					569	.1181	.0787	.1574				
					711	.2362	.1574	.2362				
					825	.2756	.1968	**.2756**				

* $\delta = \frac{pD}{400} + 1.5$

TABLE II.

No. of test.	Inside diameter.	Thickness.	Length before test.	Working pressure according to*	Expansion of pipe. At pressure of	Expansion of pipe.  A.	Expansion of pipe. B.	Expansion of pipe. C.	Length after test.	Internal pressure when rupture occurred.	Thickness at point of rupture.	Factor of safety.
	Inches.	*Inches.*	*Inches.*	*Lbs. sq. in.*	*Lbs. sq. in.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Lbs. sq. in.*	*Inches.*	*Pounds.*
5	5 11	.2362	69.21	196.27	1,422.3	.1968	.1968	.1968	69.09	2,560.1	.1771	13
					1,706.7	.3149	.3149	.3149				
					1,991.2	.5512	.3937	.4724				
					2,275.7	.6299	.5118	.5906				
					2,560.1	.7874	.8268	**.7874**				

* $t = \frac{pD}{5689} + 0.059$

Fracture at *c* 8.66 inches long and 1.02 inches wide; material, homogeneous.

TABLE III.

Number of test.	Pipes.		Rope work.									Results of tests.						Weight of pipe per running foot without flanges.		Increased weight	Increased cost
	Inside diameter.	Thickness.	Material.	Circumference.	Number of strands.	No. of wires per strand.	Total number of wires.	Thickness of wires.	Number of convolutions per foot length of pipe.	Weight of wire rope.		Tensile strength of wire rope.	Internal pressure.	Expansion of pipe due to this pressure.	Rope broke at an internal pressure of—	Pressure on the winding.	Pressure on the sides of the pipe.	Without winding.	With winding.	Due to winding.	
										Per running foot.	Per foot of pipe.										
	Inches.	*Inch.*		*Inch.*				*Inch.*		*Lb.*	*Lbs.*	*Lbs.*	*Lbs. sq. in.*	*Inch.*	*Lbs. per sq. in.*	*Lbs. sq. in.*	*Lbs. sq. in.*	*Lbs.*	*Lbs.*	*Per cent.*	*Per cent.*
6	7.87	.2952	Copper wire rope.	.5236	1	4	4	.0787	67	.0739	11.22	41,250	1,138 2,133 2,276	.03937 .3149 .3937	2,560	1,910	650	29.56	40.78	38	34.7
7	7.87	.2952	Galvanized steel wire.	.1968	1	7	7	.0216	155.7	.01908	3.709	34,138	853 1,422 1,849	0 .03937 .0787	1,920	1,849	71	29.56	32.27	12.5	7.4
8	**7.87**	.2952	"	**.2952**	3	3	9	.0196	130.8	.01317	3.870	36,980	1,422 1,707 2,133	.03937 .0787 .1181	**2,276**	1,593	683	29.56	33.43	**13**	**10**
9	7.87	.2952	"	.492	3	7	21	0248	72.5	.04502	7.391	110,940	1,422 2,560 3,698	.01968 .03937 .07874	.....	.....	.....	29.56	36.95	25	12.4*
10	**11.81**	.4133	"	**.3937**	4	5	20	.0188	94.4	.02183	6.921	62,580	1,422 1,707 2,133	.03937 .07874 .15748	**2,276**	1,294	981	61.82	68.74	**11.2**	**5.5**
11	11.81	.4133	"	.7874	5	4	20	.0413	47.5	.09743	15.6	246,050	1,707 2,133 3,413	.01968 .03937 .11811	.....	.....	.....	61.82	77.40	25	8.7†

* The winding did not break at a pressure of 3,698 pounds. † As in test 9.

TABLE IV.

No. of test.	Pipes. Inside diameter.	Pipes. Thickness.	Rope work. Manner of winding.	Rope work. Material.	Rope work. Circumference.	Rope work. No. of strands.	Rope work. No. of wires per strand.	Rope work. Total number of wires.	Rope work. Thickness of wires.	Rope work. No. of convolutions per foot length of pipe	Rope work. Weight of wire rope. Per running foot.	Rope work. Weight of wire rope. Per foot length of pipe.	Results of tests. Tensile strength of wire rope.	Results of tests. Internal pressure.	Results of tests. Expansion of pipe due to this pressure.	Results of tests. Rope broke at an internal pressure of—	Results of tests. Pressure on the winding.	Results of tests. Pressure on the sides of the pipe.	Weight of pipe per running foot without flanges. Winding. Without	Weight of pipe per running foot without flanges. Winding. With	Increased weight. Due to winding.	Increased cost. Due to winding.
	Ins.	*In.*	*Fig.*		*Inch.*				*Inch.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs. sq. in*	*Inch.*	*Lbs. sq. in.*	*Lbs. sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*	*Per cent.*	*Per cent.*
12	11.81	.4133	2	Steel wire rope.	.3937	4	5	20	.01889	94.4	.02183	22.7	970	1,422 1,707 2,133	.03937 .07874 .15748	2,489	1,294	1,195	61.81	68.73	11.2	5.5
13	11.81	.4133	3	"	.4920	8	7	56	.01377	77.7	.03561	30.42	1675.5	1,422 1,707 1,849	.07874 .1181 .1574	1,877	*	*	61.81	71.08	15.0	6.6
14	11.81	.4133	4	"	.3937	4	5	20	.01889	94.4	.02183	22.7	970	1,422 1,707 2,133	.03937 .07874 .1574	2,560	1,294	1,266	61.81	68.73	11.2	5.5
15	11.81	.4133	5	"	.3937	4	5	20	.01889	94.4	.02183	22.7	970	1,422 1,707 1,991	.03937 .07874 .11811	2,347	1,294	1,053	61.81	68.73	11.2	5.5
16	11.81	4133	6	"	**.3937**	4	5	20	01889	94.4	.02183	22.7	970†	1,280 1,707 2,418	.03937 .07874 .15748	2,418	1,294	1,266	61.81	68.73	**11.2**	**5.5**
17	7.87	.2952	6	"	**.2952**	3	3	9	.01968	131	.01316	12.69	573‡	853 2,133 2,845	.03937 .07874 .15748	2,702	1,593	1,365	29.56	33.43	**13**	**10**
18	11.81	.2952	6	"	.3937	4	5	20	.01889	94.4	.02183	22.26	970	853 1,422 1,849	.03937 .11811 .23622	1,849	1,294	555	43.67	50.46	15.5 ‖	7.4
19	7.87	.1968	6	"	.2952	3	3	9	.01968	131	.01316	12.34	573	1,280 1,707 1,920	.03937 .07874 .11811	1,991	1,593	398	19.28	23.04	19.5 ‖	14
20	7.87	.2952	6	"	.3937	4	5	20	.01889	94.4	.02183	15.43	970	853 1,422 2,560	.01968 .03937 .1181	2,987	1,934	1,053	29.56	34.26	16	10.7
21	7.87	.2952	6	Copper wire rope.	.5236	1	4	4	.07874	67	.0739	36.81	639	853 1,183 1,422 1,707	.01968 .03937 .1181 .2362	.....	910	796¶	**29.56**	40.78	38.0	34.7

* The distribution of the load on the winding and the sides of the pipe could not be established with any degree of certainty on account of the unfavorable load. † The first bight broke at 2,418 pounds; other bights broke at 2,560 pounds, and after the pipe had been distended at 1,707 pounds. ‡ The first bight broke at 2,707 pounds; other breaks occurred at 2,958 pounds per square inch. ‖ Pipes of small thickness. ‡ The thickness of these pipes at a certain place was decreased to three-fourths of its original thickness for a distance of 7.87 inches. ¶ The pipe burst at a pressure of 1,707 pounds per square inch at the weakened place without damaging the copper wire rope.

REMARKS ON STEAM PIPES.

By J. T. Milton, Esq.

[Read at the Thirty sixth Session of the Institution of Naval Architects, 1895]

The importance of having reliable steam pipes on board vessels cannot be overestimated. There have been a few cases where pipes have fractured with fatal results, which at the time drew attention to the subject; but minor accidents occur, and serious troubles with joints, &c., have to be faced, in which very little interest is taken. For instance, since the accident to the steam pipe of the *Elbe* in 1887, there have been fifteen casualties to the steam pipes of British owned vessels which have been inquired into by the Board of Trade under the Explosions Act of 1882. A list of these cases is given at the end of the paper.

The object of the present paper is to bring forward some points of interest in connection with steam pipes, with the view of eliciting, in the discussion, the opinions of those who make and those who are responsible for the maintenance of these pipes as to the best material of which to make them, and the best means to be adopted to provide for their special requirements in the way of expansion, draining, &c.

With regard to material, by far the greater number of steam pipes have been and are being made of copper, but of late wrought iron has in a few cases been used. Amongst the vessels fitted with wrought iron pipes may be mentioned the *Campania* and *Lucania*. The following list, showing the names of some Liverpool ships in which cast iron steam pipes (and cast iron feed pipes) have been in use for many years, will probably be a surprise to some of the members of this Institution, as it was to me when the information was given to me three years ago by Mr. McGregor, my colleague in Liverpool:

Name of Vessel.	*Age of Steam Pipes. Years.*
Africano,	24
Agia Sofia,	23
Ararat,	24
Arcadia,	20
Bernard Hall,	15
Britannia,	10
Laconia,	7
Lord Clive,	11
Lord Gough,	16
Macedonia,	20
Nieta,	22
Nina,	25
Palm,	21
Plantain,	16
Roumelia,	18
**Andean,*	21
**Australian,*	21
**Haytian,*	19

The almost invariable use of copper for steam pipes for so many years has produced the general impression that it is the only suitable material. It, no doubt, was originally selected on account of its non-liability to corrosion on one hand, and of its great ductility on the other. As regards corrosion, the almost invariable use of cast iron for stop valve chests and safety valve chests, as well as its frequent use for T pieces connecting copper steam pipes, and its invariable use for the slide chests and doors of the high pressure cylinders, shows that cast iron, at any rate, can be used, without misgivings on this point, in parts which, like steam pipes, are always subjected to the full pressure of the steam, while the experience of the eighteen vessels previously mentioned also bears this out. The experience with *Campania* and *Lucania*, so far as it has gone, and also of several other large

*These vessels are now broken up or dismantled, but the cast iron steam pipes were in use for the periods stated.

vessels in which they have been somewhat longer in use, shows that wrought iron pipes also give no trouble in this respect. It was, therefore, no doubt, mainly owing to the ductility of copper that it obtained, and has since maintained, the preference over other materials for steam pipes.

Steam pipes have to withstand considerable changes of temperature, and their length is consequently liable to continual alterations. Their attachment to the engine may be liable to slight alteration in position, owing to the working or vibration of the engines or vessel; while those to the boilers are also liable to small displacements, due to the contraction or expansion of the boilers from variations of temperatures. All these changes are generally taken up or provided for by the deformation of easy bends in the pipes, or by expansion stuffing boxes where the pipes are straight.

It is evident that whatever forces are necessary to produce the deformation of a length of steam pipes necessary to allow for the expansion of the pipes, or for any possible working of the engines in the vessel, these forces have to be withstood by the necks of the stop valve chests or their attachments to the boilers and to the engines. In the case of pipes of small diameters and small thickness, if the bends are easy, a moderate force may be sufficient; but if the pipes are thicker, even if the diameters and the shapes of the bends are the same, the forces required to be borne by the attachments will increase in proportion to the thickness. The same thing holds good of the flange joints between the different lengths of pipe. These have to sustain the forces brought on the end attachments, and it might, therefore, very well happen that a design suitable for steam pressure of 60 pounds may be altogether unfit for 180 pounds solely on account of the greater thickness required making the pipes more rigid.

It must be remembered that the advance of engineering of late has not only increased the steam pressures used—and, therefore, the temperatures also—but engines are, in general, of much greater size and power than those used years ago. The steam pipes now, therefore, are, as a rule, larger in diameter, much thicker, and are subject to greater changes of temperature and

expansion, &c., than formerly. These all make the pipes so much stiffer, or more rigid, that with many pipes, even when made of copper, their rigidity is so great that their yielding or altering form cannot be relied upon to relieve expansion strains, which have, therefore, to be provided for in the same way as they would need to be if the pipes were made of cast iron.

Concurrently with the trouble of providing for expansion, &c., with thick and large pipes, there arises also a difficulty in manufacturing them. The usual method of making pipes of large diameter is to make them, both bends and straights, from copper sheets, the straights, except in very large pipes, having one seam along the entire length, the bends having two seams along the sides, the saddle and back pieces being each worked up from one sheet. The seams are invariably brazed, the edges of the copper being thinned down to form a scarph. Now, the difficulty of satisfactorily brazing a joint of this description increases rapidly with the thickness. The heat has necessarily to be applied from the outside, and has to pass through the thickness of the metal to reach the brazing solder, and thus the risk of overheating the copper on the outside, and consequently burning it, is much greater with thick than with fairly thin copper. There is also a further danger of deoxidizing the copper, both in the brazing and also in the previous annealings to which the copper has to be subjected. To this, further reference will presently be made.

All these considerations have made some of our prominent engineers look with disfavor upon copper as a material for large steam pipes, and to turn their attention to iron or steel.

Endeavors have been made to introduce seamless pipes of large size for these purposes to avoid the risk of brazing. These are made by several firms, and lately, I believe, with a certain amount of success; but amongst some of the earliest of those made some serious longitudinal defects, probably arising from a local defect in the original ingot being drawn out lengthwise in the manufacture of the pipe, caused them to be looked upon with a certain amount of suspicion, besides which the great difficulty of making satisfactory bends with these large pipes

has no doubt had some influence in preventing their more general use.

While treating of bending copper pipes, it may be well to mention that the usual practice is to make bends from tubes one gauge thicker than straight pipes of the same diameter. This is, no doubt, correct practice, so long as the radius of the bend does not fall below a certain value, depending on the diameter and thickness of the pipes; but where sharp bends are made from bent tubes, a greater thickness ought to be provided. It is often assumed that in bending pipes the axis of the tube does not lengthen, and that the material of the saddle of the pipe becomes compressed to an amount about equal to the extension at the back of the bend. This is not the case. The compression of the material is not very great, and the pipe bends by extending not only at the back of the bend, but also along the sides; and if it be remembered that the thinning of the metal must be proportional to the extension, it will be found that one gauge thicker is in many cases scarcely sufficient to provide for this.

In Vol. II, page 431, of the Transactions of the Iron and Steel Institution, there is described a method by means of which seamless steel boiler tubes are made in Germany, and it is understood that a somewhat similar process is in use in this country for making seamless copper tubes. In some cases, however, these tubes are still made by repeated drawings from a cast pipe, in which case any original defect in the casting must produce a more serious defect in the finished tube.

The method of manufacturing the Elmore copper pipes has been publicly described, and it has been claimed that it renders the probability of their containing any latent defect very remote.

The results (Table I) of tests made by the Elmore Copper Company upon two tubes made by themselves, and on one seamless tube and three brazed tubes which they procured from other makers, will be of interest.

It will be observed that the seamless drawn, and also the Elmore tubes, showed a high degree of strength, which indicated that they were *hard*, or *unannealed*, a condition in which they would not be used in practice, as steam pipes are always left annealed, or very slightly hardened by planishing.

TABLE I.

Description of pipe.	Diameter inside.	Thickness.	Pressure at which pipe burst.	Stress in tons per sq. in. produced by this pressure.
	Inches.	*Inch.*	*Pounds per square inch.*	
Elmore deposited.....	12.039	.121	930	*20.65
Ditto.....	9.05	.118	1,100	†18.8
Seamless drawn.....	7.25	.125	1,520	19.3
Brazed	12.52	From .104 to .144	580	‡15.58 §12.56
Ditto.....	9.23	From .125 to .143	750	‡12.36 §11.27
Ditto.....	7.38	From .116 to .126	750	‡10.65 §10.00

NOTE.—All the brazed pipes burst by tearing at the edge of the brazing.

REMARKS.—* Pipe commenced to stretch at about 800 pounds per square inch. † Fractured at flange only. ‡ On thinnest section. § On mean section.

To show the actual strengths of the copper in an annealed condition, twenty-eight test pieces were cut from these pipes and tested in an ordinary tensile testing machine, some of them being annealed, others unannealed. The results of these tests are given in Table II.

From these tensile tests it will appear that Elmore copper, even when hard, has much extension, but that it commences to elongate at much less stress than annealed ordinary copper; while, when annealed, its behavior as to ultimate strength and extension is very similar to that of good commercial copper, but it appears to commence to elongate at somewhat lower stresses than the latter.

While treating of copper pipes it may be well to say a few words as to the qualities of copper. Engineers generally purchase their copper sheets or tubes without subjecting them to rigid tests, relying upon the reputation of the makers for supplying a good article, and not troubling about the chemical composition, &c., so long as it is found to work well. In view of the great ductility of copper, the working of even an indifferent sample of copper may not be sufficient to detect its quality, especially when made into straight or nearly straight pipes.

TABLE II.

SHOWING THE RESULTS OF TESTS OF STRIPS OF COPPER FROM THE SEAMLESS DRAWN, ELMORE DEPOSITED, AND BRAZED COPPER.

Dimensions of Test Piece.				Fractured Area.	Extension.	Stress at which Permanent Elongation was first observed.	Maximum Stress.	Remarks.
Length.	Breadth.	Thickness.	Area.					
			TESTS FROM SEAMLESS DRAWN.					
In.	*In.*	*In.*	*Sq. in.*	*Sq. in.*	*Per ct*	*Tons per sq. in.*	*Tons per sq. in.*	
7½	1.496	.127	.190	.172	0 8	10.5	21.6	Not annealed.
"	1.494	.123	.184	.165	2.5	13.06	23.4	"
"	1.497	.125	.187	.151	19.8	4.4	14.7	Annealed.
"	1.495	.125	.187	.144	20 7	4.28	15.3	"
			TESTS FROM ELMORE DEPOSITED COPPER.					
9	1.491	.118	.176	.094	22.9	2 39	21.1	Not annealed.
"	1.496	.113	.169	.082	25.6	2.25	21.2	"
"	1 493	.112	.167	.088	43.0	1.20	15.6	Annealed.
"	1.496	.115	.172	.092	43.0	3.00	15.1	"
"	1.496	.113	.169	.084	25.0	2.48	20.9	Not annealed.
"	1 496	.120	.179	.097	25.0	2.78	20.4	"
"	1.495	.117	.175	.084	43.0	1.49	15.5	Annealed.
"	1.495	.120	.179	.091	41.6	1.40	16.2	"
7½	1.495	.084	.126	.078	21.1	3.60	24.3	Not annealed.
"	1 499	.085	.127	077	20.0	2.70	24.1	"
"	1.494	.085	.127	.068	43.5	2.90	16.5	Annealed.
"	1.498	.088	.132	.066	45.6	2.40	16.2	"
			TESTS FROM THE COPPER FROM WHICH THE BRAZED PIPES WERE MADE.					
9	1.494	.135	.200	.178	19.4	3.90	17.4	Unannealed.
"	1.492	.133	.198	.124	29.8	5.90	17.8	"
7½	1.496	.121	.181	.141	28 9	4.14	16.5	"
9	1 495	.136	.200	.151	32.6	2.25	16.9	Annealed.
"	1.490	.135	.198	.117	38.8	4 10	17.2	"
7½	1.496	.123	.184	.137	31.8	3.80	15.5	"
			TESTS FROM BRAZED PIPES CUT ACROSS THE JOINTS.					
9	1.488	.110	.164	.175	2 4	3.30	14.0	Unannealed.
"	1.490	.135	.200	.126	13.9	3.75	15.35	"
7½	1.492	.121	.180	.144	2.4	3.33	13 06	"
9	1.492	.112	.167	.163	2 8	2.09	14.10	"
"	1.490	.134	.199	.146	20.1	2.56	14.5	Annealed.
7½	1.496	.120	.179	.134	12.9	3.65	12.6	"

All but the last test broke at edge of brazing. The last test broke partly at edge and partly through the brazing.

MEAN RESULTS.

	Tensile strength.	Tons per sq. in.	Extension per cent.
Elmore copper.....	Annealed	15.85	43.3
	Unannealed	22.0	23.3
Seamless drawn.	Annealed	15.0	20.07
	Unannealed	22.5	1.65
Ordinary copper.....	Annealed	16.53	34.4
	Unannealed	17.23	26.0
Brazed joint.....	Annealed	13.55	...
	Unannealed	14.10	...

Commercial copper is practically never pure, the amount of different impurities found in it being probably greater than in the case of any other metal commonly used. Information on this question can be found in the Transactions of Mechanical Engineers, No. 2, 1893, where two papers will be found on the subject, by Professor W. C. Roberts-Austen and Mr. Wm. Dean, respectively. An opinion is generally held by locomotive engineers, coppersmiths, and many others, that the commercial copper of the present day, although chemically purer than that of years ago, is inferior in respect to its lasting qualities, both as regards ability to resist corrosive influences and also to withstand fatigue without cracking. Accordingly, for some purposes, what may be termed impurities are added to the copper for the purpose of improving some of its properties. The papers referred to, and the discussion on them appear to show that arsenic up to a proportion of $\frac{1}{2}$ per cent. is certainly not injurious and is probably beneficial, improving both the tensile strength and ductility of the copper. On the other hand bismuth is objectionable, even small quantities, such as .1 per cent., being sufficient to make the metal absolutely unreliable when heated above the boiling point of water. The following figures extracted from the paper by Professor Roberts-Austen, show these points.

Particulars are given in the Table on the following page for comparison of pure copper and of copper containing arsenic or bismuth, in all cases the copper being as cast, not hammered.

A small quantity of lead, say under .1 per cent., does not appear to be objectionable, but large quantities are not desirable; on the other hand, it appears that nickel and silver are not detrimental, the samples quoted by Mr. Dean as containing the largest proportions of these elements having given satisfactory results in use.

It is rather singular that in all copper made by smelting, oxygen is required in the copper to give ductility; the actual amount required in any case varies apparently with the proportions and amounts of the various impurities present. The precise amount needed is ascertained by frequent tests made during the "poling" process. If less than sufficient oxygen is present,

the copper is called "over-poled," and is deficient in ductility, while if the oxygen is in excess, and the copper "dry," as it is termed, ductility also is lost. When the exact proportion is present the copper is termed "tough," or "tough pitch," and is ductile.

	Temperature of copper.	Tensile strength per square inch.	Percentage of elongation.
	Deg. Fahr.	*Pounds.*	
Pure copper	64	18,450	20
Do	64	19,740	35
Copper containing 1.2 per cent. of arsenic	68	24,840	20
Do	266	20,470	16.6
Do	435	16,460	15
Do	511	14,340	4
Do	655	14,860	10
Copper containing 1.5 per cent. of arsenic	59	26,460	20
Do	64	25,400	25 to 50
Do	241	23,460	26
Do	419	19,450	37
Do	500	18,360	Irregular.
Do	586	15,030	0
			Percentage of elongation in 4 inches.
Copper containing .1 per cent of bismuth	59	18,020	20
Do	214	11,510	15
Do	324	5,620	0
Do	390	3,860	0
Do	525	4,940	0
Do	558	2,770	0

A point not generally appreciated by coppersmiths is, that copper of the proper "pitch," that is to say, containing the exact proportion of oxygen to give it its proper ductility, can be made to give up its oxygen and to become in fact "over-poled" by heating it in a reducing flame; that is, a flame not fully charged with oxygen. On the other hand, by heating it in an oxydizing flame, it does not appear to absorb oxygen into the body of the material, the oxygen remaining on its surface, combined with some of the copper, in the form of oxide scale. If, therefore, copper is annealed or brazed, or worked in any way in a reducing flame, it loses its "pitch," and this cannot subsequently be

regained by reheating in an oxydizing flame. This matter was strongly impressed upon me by Dr. Watson, of the Broughton Copper Company, to whom I am indebted for much information on copper, and from experiments on this point I am of opinion that many of the so-called "burnings" of copper arise from heating in a reducing flame, rather than from overheating, or being raised to too high a temperature.

Inasmuch as the proportion of oxygen required to produce the proper "pitch" in copper varies according to the composition of the copper, the liability of its losing pitch during working will probably be much greater in some qualities of copper than in others.

It has been stated that the tensile strength and ductility of copper vary according to its composition, but with the same mixture of metal they vary very much more with the mechanical treatment it undergoes. If properly annealed its tensile strength is comparatively low, and its ductility is high. In comparing the qualities of copper, therefore, it is necessary to fix the standard as being thoroughly annealed. To show the effect of annealing and of work the following tests recently made may be quoted. A copper tube was drawn in one operation from 3 wire gauge to 11 wire gauge (a very excessive draw, more than doubling its length). Its tensile strength when drawn was 24.38 tons per square inch, but its elongation was only 3.1 per cent. in 4 inches. After annealing (or possibly only partial annealing) its tensile strength was 16.66 tons per square inch, and its elongation was 44 per cent. in 4 inches. A good average result with annealed copper is 14 tons per square inch, and 40 to 45 per cent. elongation in 4 inches. Some other illustrations of the effect of annealing on tensile strength, &c., are given in the results of the tests made by the Elmore Company, already quoted.

While treating on annealing, it is interesting to compare the difference in the methods adopted in tube works and in ordinary coppersmiths' shops. In the former the tubes are annealed after every draw. They are raised to a temperature of from 800° to 900° C., say from 1,500° to 1,650° F., and are kept at that tem-

perature for some little time, after which they are quenched in water.

The tubes are uniformly heated over their whole length, care being taken that the flame is clear and contains an excess of oxygen. In the coppersmith's shop, both sheets and pipes are heated over open coke fires; the flame may possibly be reducing, that is, may have a deficiency of oxygen, if the fire is a thick one. The sheet or pipe is moved about over the fire, spot after spot being heated, generally to a dull red, and after the whole surface has been thus treated the copper is either quenched or allowed to cool and is considered to be annealed. It thus depends upon the workman's care and judgment to ensure that every part has been heated, and there is considerable probability that some small part may escape full heating. Further, the heating cannot be uniform, nor can any part in general be retained at the red heat for any considerable time, nor is the temperature at any part raised to the same degree as is usual in tube works.

The influence of time upon annealing has, so far as I know, not been much experimented upon, neither has that of the various impurities; but I am informed by Dr. Watson that annealing may be efficiently carried out at lower temperatures than 800° C., but that it requires longer time at the lower temperatures than at the higher.

To show the influence of temperature upon annealing the following experiments are deserving of notice. A sample of copper was found to be abnormal in its behavior, being brittle instead of ductile. Its composition was as follows:

Copper	99.693
Nickel	.260
Iron	.027
Arsenic	Trace.
Silver	.020
	100.000

Six test pieces were cut off it, one was tested unannealed, and five were annealed at different temperatures. The following were the results:

Temperature at which annealing was performed.	Tensile strength tons per sq. in.	Extension per cent. in 4 in.	Fracture.
Unannealed	14.9	0.0	Granular.
Faintly visible red, about 525° C.	12.13	6.2	"
Dull red, about 700° C.	11.78	3.1	"
Cherry red, about 850° C	13.89	4.7	"
Bright red, about 900° C.	14.2	14.0	Silky.
Approaching yellow, 1,000° C.	15.64	25.0	"

I am not able to say what caused the abnormal brittleness in this case, but after annealing at the high temperature the material regained a fair amount of ductility; and, after subsequent drawing or cold rolling, behaved in a perfectly normal manner. Annealing, however, at red heats left the material brittle. In this case very little time was allowed for annealing, the test pieces having been heated in an open fire and then quenched, the influence of time on annealing not having been so fully appreciated as it should have been.

The following figures, taken from page 310, Vol. II, 1894, of the Transactions of the Iron and Steel Institute, giving the temperatures corresponding with different visible appearances of heated metals are of interest:

	Deg. Cent.		Deg. Fahr.
Incipient redness	525	=	977
Dull red	700	=	1,292
Cherry red	850	=	1,562
Bright red	950	=	1,742
Yellow	1,100	=	2,012
Incipient white	1,300	=	2,372
Bright white	1,500	=	2,732

That copper for large steam pipes is now being looked upon with some distrust is evidenced by the Admiralty having such pipes bound round with wire, whilst in mercantile practice some firms put iron bands round the pipes every few inches, and in some cases the pipes are lapped with fine steel wire ropes.

Turning our attention to other materials suitable for steam pipes, we find, practically, only three, viz: cast iron, wrought iron and mild steel.

Cast iron has the advantage that it can be made in any shape, straight or bent, and that tees or junctions can be made of it.

On the other hand, if the pipes are of the same strength as wrought iron or steel, they are much heavier.

Wrought iron and steel may both be made with a lap welded joint, but, whereas welds in iron are apparently looked upon as trustworthy after a severe hydraulic test, those in steel do not appear to have the same confidence reposed in them, as they generally have a riveted butt strap fitted over them. Apparently, therefore, iron pipes are preferable to steel, unless the latter are made seamless.

With pipes of either iron or steel, manufacturing conditions appear to require them to be of such a thickness that either has a very large margin of strength compared with the pressures now being used, or even with those higher pressures to which marine engineering appears to be tending, so that there is no advantage in this respect in using steel rather than iron.

The question of flanges for iron pipes is important. Most of those hitherto used have had forged iron flanges screwed on, riveted over on the face of the flange, but flanges are now being electrically welded to the pipes in some cases, and welded by machine hammers in others, these plans apparently giving sound results without the chance of leakage which screwed flanges might develop.

Regarding provision for expansion of pipes, whether of copper, iron, or steel, a point sometimes lost sight of is, that it is not sufficient to provide a faucet joint in a straight length of pipe, but provision must also be made to anchor the ends of the length of pipe for the expansion of which provision has to be made, and so compel the movement of expansion to take place in the part provided for it, otherwise the end pressure on the pipes, amounting to several tons in all but the smallest pipes, will cause the joint to slide in the wrong direction. This has occasionally been overlooked in pipe designs. It is always difficult to provide for the expansion of large bends without producing excessive strains, so that, as far as possible, pipes should be made straight.

The only other point to which reference will be drawn is that of providing means of draining steam pipes. More than one

fatal accident has been thought to be due to the presence of water in the pipes. In cases where it is the practice to always raise steam in all the boilers simultaneously, the stop valves on the boilers, if opened before steam is raised, may be the best possible drains for the pipes; but where there is more than one boiler in a vessel it may often happen that, even if all the boilers are invariably used for steaming purposes, one only may be used in port for auxiliary purposes, and in this case leakage from its main stop valve will find the steam pipes leading to the other boilers receptacles for the condensed steam, which, if not drained, may be dangerous when opening the stop valves when raising steam in the other boilers. It is noteworthy that more than one of the serious accidents with pipes has occurred at the instant when stop valves were being opened.

Too much attention cannot be paid to the provision for draining steam pipes, and it is considered that it is preferable that these should be automatic, or such as not to require personal attention.

LIST OF CASES IN WHICH INQUIRIES HAVE BEEN HELD BY THE BOARD OF TRADE AS TO THE CAUSE OF CASUALTIES TO STEAM PIPES OF BRITISH VESSELS SINCE THE CASE OF THE S.S. *ELBE* IN 1887.

1888, *Erin*.—Wrought iron pipe connecting top of water gauge to boiler corroded, and burst. This pipe was apparently twenty years old.

1888, *Bryn Glas*.—Intermediate stop valve cover broke, attributed to the wheel for opening the valve being turned the wrong way.

1890, *Springbok*.—Main steam pipe of copper—6 inches diameter, $\frac{3}{16}$ inch thick—broke away from flange next the boiler stop valve, due to faulty construction and to imperfect repairs.

1890, *Jumna*.—Main steam pipe of copper burst at the lap in a bent portion near the boiler stop valve, probably due to defective workmanship in the original brazing.

1891, *Number Three*.—5½-inch copper steam pipe burst at the brazed joint of the bend near throttle valve. The brazing

was thought to be defective, and the accident was attributed to the presence of water in the pipe.

1891, *Greencastle.*—Steam pipe broke at the flange joining throttle valve. An expansion joint was fitted, but it was not so arranged as to take the strain off the flange.

1891, *Rohilla.*—Copper pipe, 14 inches in diameter, failed at the seam, which was riveted and brazed. Accident was attributed to an accumulation of water in the pipe.

1891, *City of Lincoln.*—Copper pipe, 6½ inches diameter, cracked through the solid copper at the edge of brazed seam. Accident was attributed to the presence of water in the pipe, and to the existence of old flaws in the copper.

1892, *Shannon.*—Branch steam pipe of copper, 8 inches in diameter. Accident was attributed to the impact of water in the pipe, set in motion by the admission of steam from an auxiliary boiler.

1892, *Vulcan.*—Main steam pipe, 6 inches diameter, failed at brazed seam, after being in use five years. Probably due to the development of a latent defect, and possibly through want of sufficient provision for expansion, &c.

1892, *Grimsby.*—Main steam pipe, 9$\frac{1}{16}$ inches diameter, burst at a part adjacent to the brazed seam. Casualty was attributed to water in the pipe being set in motion when the stop valve was opened.

1892, *Astrion.*—Copper T-piece exploded at the junction of two 6-inch pipes with one of 9 inches. Failure was attributed to the movement of the boilers and to the expansion joint having become set fast.

1892, *Viola.*—Stop valve box (cast iron) burst. Accident was attributed to the accumulation of water in the steam pipe, the draining arrangements having been allowed to get out of order.

1893, *Othello.*—Small steam pipe, 1¼ inches diameter, burst by tearing away from the flange. Attributed to vibration of engines.

1893, *Astrakhan.*—Winch steam pipe broke, due to water in the pipe being set in motion when steam was turned on.

After the reading of Mr. Milton's paper, the Elmore Company expressed surprise and doubt as to the accuracy of the figures given in the paper as representing the elastic limit of their material, and had some tests made by Professor Unwin, in the presence of Mr. Milton, which show that the material supplied by them possesses a high ratio of elastic limit to ultimate strength. The samples tested were what the makers term "soft deposited copper," which, they claim, will stand all the ordinary working of the coppersmith without annealing. The results of the tests, which were published in "Engineering," are given in the following table:

[Copy.]

CITY AND GUILDS OF LONDON INSTITUTE.

Engineering Laboratory, Central Institution, Exhibition Road, London, S. W. Date May 10, 1895. Report on Specimens of Copper received from W. Elmore, Esq., on May 7, 1895.

Test number.	Marks on specimen.	Dimensions in inches.		Section in square inches.	Stress at elastic limit in tons per square inch.	Maximum stress in tons per square inch.	Elongation in 8 inches.
		Width.	Thick.				
							Per cent.
1650*	C.	1.469	0.187	0.2747	2.275	13.09	45.88
1651	C.	1.485	0.1895	0.2814	15.10	15.48	13.13
1652	C.	1.503	0.185	0.2781	15.28	15 91	14 75
1653	L.	1.500	0.1935	0.2903	15.07	15.67	21.25
1654	L.	1.498	0.193	0.2891	15.56	16 03	17.88
1655*	L.	1.503	0.188	0.2826	1.769	13.13	48 13

* Annealed.

(Signed) W. C. UNWIN,
Professor of Engineering.

FURTHER EXPERIENCE WITH FIRST CLASS BATTLE SHIPS.

By Sir William White, K.C.B., LL.D., F.R.S.

[Read at the thirty-sixth session of the Institution of Naval Architects.]

In the paper read before the Institution last year, "On the Qualities and Performances of Recent First-class Battleships," I summarized the experience gained up to that time with vessels of the *Royal Sovereign* class. In the present communication it is proposed to put on record some results of further experience gained during the past year, and certain facts of great professional interest obtained from rolling experiments made on the *Revenge* at Spithead. The reasons which led to the decision not to fit bilge keels to the *Royal Sovereign* class during construction were stated last year, but may be briefly recapitulated. In ships of these large dimensions and great inertia, it was anticipated, on the basis of previous observation and experiment, that any practicable bilge keels which could be added would have a relatively small steadying effect. The presence of bilge keels, even of moderate depth, necessarily interfered with facilities for docking the ships in some of the docks which they would have to enter. Further, it was estimated, and experience has confirmed the estimate, that in their period of oscillation the *Royal Sovereign* class would approximate to the *Inconstant*, *Hercules* and *Sultan*, which had a high reputation for steadiness at sea. The *Hercules* and *Sultan* had only shallow side keels from 9 inches to 10 inches deep, two on each side, as shown in Fig. 4.

The question was carefully discussed in all its bearings when the design was under consideration. It was realized that some steadying effect would be obtained by fitting bilge keels. But it was finally decided that the balance of advantage lay on the side of omitting bilge keels until experience had been gained at sea.

That stage had been reached when last year's paper was read. I then stated that, as an experiment, the *Repulse* had been fitted with bilge keels so that she might be tried in company with sister ships belonging to the Channel Squadron. These keels are shown in Fig. 4. They are about 200 feet in length and 3 feet deep.

FURTHER TRIALS AT SEA.

The first opportunity for comparative trial occurred in June, 1894, when the squadron was cruising off the west coast of Scotland. A long, low swell was encountered with a length said to vary from 300 feet to 400 feet (crest to crest) and a period estimated at 10 to 12 seconds. For some time this swell was on the quarter, and the speed and course of the ships relatively to the swell were such as produced heavy rolling. This occurred during the night. The reports from some of the ships state that batten observations of the horizon could not be made. Pendulum observations were, therefore, had recourse to, although they are notoriously untrustworthy. After making all allowance for possible exaggeration in the pendulum observations, the facts reported indicated conclusively the very great value of the bilge keels in the *Repulse* in reducing her arc of oscillation. This will appear from the following summary:

The *Resolution* (without bilge keels), by orders from the Admiralty, had been purposely kept in very nearly the same condition of stability as the *Repulse*. Comparing the returns from these two ships, it appears that the *Resolution* on one occasion reached a maximum inclination to the vertical of 23 degrees; whereas the *Repulse* never exceeded 11 degrees. The mean angles of oscillation were, of course, considerably below these maxima, probably about one-half. The *Royal Sovereign* and *Empress of India* were also in company. The condition of coal stowage in these two ships at the time gave them greater stiffness and a quicker period, which, under the conditions of weather and sea, caused rather heavier rolling than in the *Resolution*.

In view of this experience, although the trial was limited and not representative of many conditions occurring at sea, it was

decided to fit all the other ships of the class with bilge keels similar to those which had proved so effective in the *Repulse*. This work was completed for the ships of the Channel Squadron during their annual refit last summer; it has since been carried out in all the other ships of the class.

On the cruises of the Channel Squadron which have taken place since bilge keels were fitted, there have been but few opportunities of obtaining proof of their practical value. So far as experience has gone, however, there is a concensus of opinion amongst officers in command that rolling has been greatly reduced by the bilge keels. On one or two occasions, when it has been possible to test their value in rough water, the results obtained have been remarkable.

As an example of many communications which have reached me, I will refer to one having special interest, permission having been given me to do so by the writer, the late Captain Hall, of the *Resolution*. He wrote as follows from Vigo on January 13, 1895:

"We had a rough passage here from Gibraltar, falling in with a strong gale ahead with a heavy sea; waves from 27 feet to 30 feet in height. The difference in the behavior of this ship was marvellous. Had we been without bilge keels, we should have rolled considerably. As it was we hardly rolled at all. No fiddles were required on the table, and, except for the pitching when 'down helm,' one would not have known he was at sea, certainly not in a gale. The ship is now one of the steadiest in the service. The other battleships in the squadron were equally steady."

At our last interview in March (only a few days before his lamented death) Captain Hall told me of another critical trial which he had made with the *Resolution* while at target practice. The ship was placed broadside on to waves having a height of about 25 feet from hollow to crest and a period approximately synchronizing with her own. The maximum angle of inclination noted under these trying conditions was 6 degrees to 8 degrees on either side of the vertical, and the whole of the guns on the main deck could be fought with perfect freedom. Captain

Hall was of opinion from previous experience that the *Resolution*, without bilge keels, under similar circumstances, would have reached occasionally maximum inclinations to the vertical of 16 degrees to 18 degrees. Further experience will, of course, be gained in the actual service of the vessels now that they have bilge keels. This will enable a more complete estimate to be formed of their behavior when exposed to those conditions of a low and synchronizing swell which occasionally caused heavy rolling in the earlier periods of their service before bilge keels were fitted. All the facts in regard to that earlier experience were given in my paper of last year.

It must be frankly admitted that the steadying effect of bilge keels as fitted on the *Repulse* and her sister ships has greatly exceeded that which we had anticipated from previous experience and experiment.

As I remarked last year, no one has more strenuously urged the utility of bilge keels than myself. The practical question which had to be decided, however, was whether the extent of that steadying effect in the *Royal Sovereign* class was likely to compensate for the inconvenience in docking necessarily resulting from the presence of bilge keels on such large ships. That question was set at rest by the relatively better behavior of the *Repulse* in June, 1894, and by the experience since gained in the Channel Squadron. The broad test of actual experience at sea is, of course, sufficient and conclusive for practical purposes.

ROLLING EXPERIMENTS MADE ON THE *REVENGE*.

For scientific purposes, and for guidance in future designs, much more exact information was required than could be obtained from observations of the behavior of ships under actual conditions of service. There must necessarily be variations of stowage, stability, and other features influencing oscillation, even in sister ships. Ships in company are not always simultaneously exposed to identical conditions at sea. Only long-continued experience, in fact, can suffice to determine the relative behavior of different ships. From the scientific side the problem could

only be solved by still-water rolling experiments. It was arranged, therefore, that these should be carried out on the *Revenge*, which had been built and engined by the same firm as the *Resolution*. A careful programme was prepared, and the experiments were conducted by Mr. R. E. Froude. The first series was made before bilge keels were fitted, and the second after that work was completed.

In each series it was proposed, so far as practicable, with some of the equipment weights necessarily not on board, to roll the ship in her condition of maximum stability, and in a condition of stability approximating to the minimum stability likely to be reached on service. In other words, the stowage of coal and water was so varied as to give a metacentric height varying from 3¼ feet to a little over 4 feet. Trials were also made after the bilge keels were fitted, with the ship under way as well as with no headway.

During each of the first three trials an inclining experiment was made by running in and out the barbette guns when trained abeam, to determine accurately the metacentric height associated with the several experiments. For the fourth trial the metacentric height was calculated from the known differences in weights carried as compared with previous trials. The oscillations of the ship were produced by training the heavy guns at a suitable rate from side to side, and by running men across the deck in the usual manner. The particulars of the trials which took place at Spithead in deep water with the ship drifting freely and also under way, are set out briefly in the following tabular statement:

	First trial.	Second trial.	Third trial.	Fourth trial
Date of trial	Oct. 3, '94	Oct. 30,'94	Jan.15,'95	Feb.13,'95
Mean draught of water, feet and inches	27–6	26–0½	26–0½	27–11½
Displacement, tons	14,300	13,370	13,370	14,620
Metacentric height, feet	3.78	3.25	3.29	3.86
Mean period of single swing, seconds	7.6	8.0	8.4	7 75
Weight of coal and water on board, tons	1,485	572	536	1,782
Number of men for rolling ship	320	0	350	370

Bilge keels were fitted to the ship between the second and third trials. The effect of their addition is allowed for in the mean draught and displacement figures in the table. They were 200 feet long, 3 feet deep throughout their length, tapering away at the ends, about 1,170 square feet in collective area, with a mean radius from the C G of ship of about 41 feet for the third trial, and about 40¼ feet for the fourth trial (see Fig. 4). The results of these experiments are shown in Fig. 1 in the form of "curves of declining angles," corresponding to the curves which the late Mr. Froude published about twenty years ago for a number of representative ships of the Royal Navy, and which he then termed "curves of extinction." Each of the curves shown in the diagrams for the *Revenge* without headway gives the mean results of four or more separate sets of observations. For two of the trials, where alone it appeared necessary, they have been corrected by Mr. R. E. Froude, for variations in wind force, on the basis of experimental data obtained during these trials.

Abscissa values correspond to the number (n) of successive "swings," say, from port to starboard, or *vice versa;* which may begin to count at any point in the base line. If the rolling be isochronous, as it practically was in the *Revenge* without bilge keels, if not with them, the abscissa may also be interpreted by a scale of time. Ordinate values represent the extreme inclination (θ) to the vertical for each successive swing. On this diagram also have been shown the corresponding curves obtained by the late Mr. Froude for H. M. ships *Inconstant* and *Sultan*. The curves are so readily interpreted that it will suffice to make a brief statement indicating the *relative losses of swing* sustained by the *Revenge* with and without bilge keels.

Starting from an angle of inclination of 12 degrees to the vertical, it will be seen that in order to reduce the corresponding inclination to 6 degrees, the *Revenge* without bilge keels required to make 18 or 20 swings, and the *Sultan* about 17.

It will be observed from Fig. 1 that there is a remarkable similarity between the curve of declining angles of the *Sultan* and that for the *Revenge* without bilge keels.

Starting from an angle of inclination of 6 degrees to the ver-

tical, it required about 45 to 50 swings in the *Revenge* without bilge keels to reduce the corresponding angle of inclination to 2 degrees; whereas, after bilge keels were fitted, an equal reduction in angle was obtained by only eight swings, indicating the enormous extinctive effect of the bilge keels.

For the *Sultan* and *Inconstant* 32 and 20 swings respectively would be required to produce the same reduction. The comparison between the *Revenge*, with and without bilge keels, may be made in another way. Starting from an inclination of 6 degrees from the vertical, after 18 swings the extremes of inclination reached would be $3\frac{3}{4}$ degrees without bilge keels and 1 degree with them. Another striking illustration of the extinctive effect of bilge keels is to be found in the comparatively small oscillations impressed upon the *Revenge* after bilge keels were fitted. The ship could be rolled up to an angle of inclination of 13 degrees to the vertical by moving her barbette guns from side to side in due relation to the oscillations of the ship before bilge keels were fitted. After they were fitted, it was found difficult to exceed an inclination to the vertical of 6 degrees to 8 degrees, even with 300 to 400 men running across her decks and acting in conjunction with the movement of guns.

The variations in the "periods of swing" (from out to out) brought to light by these trials are instructive. Without bilge keels the rolling was practically isochronous at the large as well as the small angles. The period for a single swing was 7.6 seconds for the maximum stiffness and 8 seconds for the minimum stiffness, for large as well as small arcs of oscillations. After bilge keels were added, within the range of experiments up to a swing of about 12 degees (6 degrees on each side of the vertical) the period of a single swing decreased as the angle of inclination became smaller. Put into figures it was reduced by one-fifth of a second (about $2\frac{1}{2}$ per cent.) in going from a mean inclination to the vertical of 5 degrees to one of 1 degree. Further, as between the second and third trials—when the conditions of the ship as regards stowage of weights, &c., were practically identical, and when therefore the metacentric heights and radii of gyration of the ship and her lading were appreciably unchanged—there

was an increase of about 5 per cent. in the period due to the action of the bilge keels. An increase in period under these circumstances confirms results obtained in similar experiments made by the late Mr. Froude on a model of the *Devastation*, and by MM. de Benazé and Risbec on the *Elorn*. For the *Devastation* the increase in period varied from 7 to 12 per cent.; according as the depth of bilge keels was increased from 1 foot 9 inches to 6 feet. In the case of the *Elorn* (from particulars published in "Naval Science" for 1875) there was an apparent increase of about 7 per cent. in the period; the real increase, after correction for the different metacentric heights on the two occasions (*i. e.* with and without bilge keels) was about $5\frac{1}{2}$ per cent. The bilge keels in this case were about 30 feet long and 1 foot 8 inches deep on a vessel 82 feet long, mean draught about $6\frac{1}{2}$ feet and displacement 100 tons.

The addition of bilge keels, even to as large and heavy a ship as the *Revenge*, does therefore sensibly lengthen the period of oscillation under otherwise exactly similar circumstances. This increase in period, of course, tends to increased steadiness under most conditions at sea.

A feature of great interest in Fig. 1 is to be found in the increased extinctive effect of bilge keels when the ship had headway as compared with their effect when she had no headway.

It will be remembered that this matter was made the subject of experiment by M. Bertin on the *Navette*. The results have been published by M. Bertin, and reproduced in English publications. They are briefly as follows:

Speed of ship.	Value of N.
Nil	.0109
4 knots	.0123
8 knots	.015

To understand these figures it should be stated that, according to the French authorities, the rate of extinction is best expressed by the equation:

$$-\frac{d\theta}{dn} = N\theta^2$$

for angles of inclination (θ) from the vertical exceeding 3 degrees.

The late Mr. Froude also drew attention to the point in his discussion of the behavior of the *Devastation* at sea, although it is understood that no exact measures of the added extinctive effect due to headway were obtained by him in the course of his rolling experiments.

The experiments with headway with the *Revenge* included only one set at each of the two speeds tried; the results under way are therefore probably not so definite as those for the ship without headway. Still they are very suggestive, and confirmatory of the conclusion from previous experience that the rate of extinction is sensibly increased by headway, the ship entering undisturbed water while oscillating, and the inertia of that undisturbed water having to be overcome. For example, starting at 5 degrees from the vertical in each case, the angles of inclination reached after a certain number of swings were as follows:

	Speed of ship.		
	Nil.	10 knots.	12 knots.
After 4 swings, degrees	2.95	2 35	2.2
After 8 swings, degrees	1.95	1.12	1.05
After 12 swings, degrees	1.45	.55	.45
After 16 swings, degrees	1.15	.20	.25

The experimental results are shown in different form in Fig. 2, which contains "curves of extinction" obtained by differentiation from the corresponding curves of declining angles shown in Fig. 1. The equations to these curves of extinction are given in Note I of the Appendix.

Abscissa values here represent angles of inclination (θ) from the vertical in degrees; ordinates represent the extinction value $\left\{-\frac{d\theta}{dn}\right\}$, or the angle from the vertical lost per swing. In this case also the curves are so easy of interpretation that it is unnecessary to say much respecting them, but they illustrate perhaps more clearly than those of "declining angles" (Fig. 1) the enormously increased rate of extinction with bilge keels. Taking a total swing of 10 degrees (say from port to starboard), we have

an abscissa value of 5_2—the mean of the angles of inclination to the vertical at the beginning and end of the swing.

The relative extinction values possessed by the *Revenge*, *Sultan* and *Inconstant*, are given by the following tabular statement. The extinction value of the *Revenge* at deep draught, with no bilge keels, is taken as unity for purposes of comparison.

Sultan	speed of ship, nil,	1.4
Inconstant	" " " "	2.4
Revenge, deep draught, no bilge keels	" " " "	1.0
light draught, no bilge keels	" " " "	1.2
light draught, with bilge keels	" " " "	7.3
deep draught, with bilge keels	" " " "	6.0
deep draught, with bilge keels	" " " 10 knots	8.5
deep draught, with bilge keels	" " " 12 knots	10.3

This comparison is approximately correct for any other angle of inclination within the range of the experiments, except for the *Revenge* under way. The loss of range per swing for moderate abscissa values (up to 6 degrees) will be seen to be about *six times* as great with the bilge keels (whether at deep or light draught) as it was before they were added.

When a ship is rolling permanently through a certain arc, the external forces impress upon her during each swing an amount of energy exactly balancing the energy corresponding to the work done by all the forces resisting her oscillation. This work is expressed and measured by the ordinate of the curve of extinction corresponding to the extent of swing (see Fig. 2).

If for any ship we have two curves of extinction, one with and the other without bilge keels, then for a *given ordinate value*—or energy corresponding to work done by the external forces resisting oscillation—the respective abscissa values corresponding to that ordinate on the two curves, will of course differ. That is to say, the abscissa value (or swing) for a given "extinction" will be less for the curve with bilge keels than for the curve without them. The difference of the abscissæ may be taken, therefore, as a measure of the probable reduction in swing from the vertical due to the addition of bilge keels under the action of external forces capable of producing the larger swing without bilge keels.

Applying this to the case of the *Revenge*, and extending upwards her curves of extinction without bilge keels (by using the appropriate equations), let it be assumed that some external forces—say a series of regular co-periodic waves—could produce a permanent swing of 18 degrees on each side of the vertical. Then the same external force applied to the ship with bilge keels would only produce a swing of about 6 degrees. The addition of bilge keels, therefore, roughly speaking, would reduce the swing to one-third of its former amount. This ratio is practically constant for angles less than 18 degrees, as may be readily seen on referring to Fig. 2.

This is an extreme comparison for the conditions of maximum steady rolling, viz: a series of regular co-periodic waves which are seldom met with, and do not obtain for any length of time. Any slight disperiodicity is accompanied by a rapid decrease in the magnitude of the swings, as was demonstrated by the late Mr. Froude. Into this branch of the subject it is impossible to enter at present, and it is unnecessary for purposes of illustration of the great extinctive effect of bilge keels demonstrated in the experiments on the *Revenge*. The results of these experiments have added greatly to our knowledge of the subject of bilge keel resistance, but they must necessarily be supplemented by much fuller investigation and experiment before the subject can be considered to be exhausted. It is proposed that this question shall be followed up in all its details by Mr. R. E. Froude, in whose hands we may be sure it will receive most able and thorough treatment.

ESTIMATE FOR EXTINCTIVE EFFECT OF BILGE KEELS MADE PRIOR TO ROLLING EXPERIMENTS ON *REVENGE*.

In justification of the opinion which we had formed previously to these experiments, in regard to the probably small steadying effect of bilge keels on a ship of the *Royal Sovereign* class, it appears desirable to add a brief statement. The best information hitherto accessible on the subject of keel and bilge keel resistance to rolling is undoubtedly to be found in the papers published by the late Mr. Froude in *Naval Science* (1872–'74).

In his calculations for several typical ships which had been made the subject of still water rolling experiments, Mr. Froude had occasion to estimate the work of the resistance to a flat surface (such as a bilge keel or a portion of the deadwood) oscillating harmonically in water. For this he adopted, as applicable to the case in question, a coefficient of 1.6 pounds per square foot with a mean velocity of 1 foot per second. This coefficient, Mr. Froude stated, was based upon experiments made with a powerful pendulum apparatus carrying a plane so deeply submerged as to be clear of all wave making action. The purpose which Mr. Froude then had primarily in view was to authenticate the opinion that wave making resistance was a most potent factor in fluid resistance to rolling. That position he thoroughly established.

In his analysis of the total work represented by the observed extinction of oscillation in certain typical ships, he showed incidentally that the use of this coefficient of 1.6 pounds per square foot for deadwood and keels, in association with his estimate for frictional resistance on the immersed surfaces of the ships, did not fully account for the experimental facts. On the other hand, in the case of the *Sultan* the agreement between Mr. Froude's estimate, based upon the use of this coefficient, and the experimental facts was very close indeed.

Another valuable contribution to the subject is to be found in the appendix to a paper contributed by Mr. Watts to the "Proceedings of the Institution for 1883." In this paper Mr. Watts endeavored to estimate the area of bilge keels required to secure a given rate of extinction in a certain ship. For this purpose he employed experimental data obtained by the late Mr. Froude from the *Greyhound*, with and without bilge keels. From the figures published by Mr. Froude in "Naval Science," for the *Volage*, *Inconstant* and *Sultan*, Mr. Watts obtained certain approximate values for the coefficients of normal pressure on bilge keels when oscillating, on the assumption that the whole difference in the work of extinction between that estimated by Mr. Froude and that deduced from the experiments on typical ships might be credited to a virtual increase in the coefficients of resistance per unit of surface of the bilge keels. Taking the *Volage* and

Inconstant for example, Mr. Watts estimated that, instead of the coefficient 1.6 pounds per square foot for a mean velocity of 1 foot per second, the respective coefficients would become 8.7 and 7.2 pounds respectively. In the case of the *Sultan*, however, the coefficient thus derived from the rolling experiments was shown to be as nearly as possible 1.6 pounds. The *Sultan* was fitted with duplicated shallow side keels (as shown in Fig. 4), and that fact probably had much to do with the close agreement of the estimate and the experiment.

Our difficulty in dealing with the question of probable bilge keel effect on the *Royal Sovereign* class before experiments were made was twofold:—

(1) We did not know the character of the curve of extinction for the ships without bilge keels.

(2) We were uncertain as to the coefficient to be used in estimating the additional resistance due to bilge keels of a specified length, depth, area and mean radius of oscillation.

The first difficulty might have been met by recourse to model experiments. It was not considered necessary, however, to carry out such experiments, since the addition of bilge keels at a later stage was a simple matter, should they prove necessary. Moreover on the basis of experience with ships like the *Inconstant*, *Hercules* and *Sultan*, it appeared reasonable to expect that the *Royal Sovereign* class, under most conditions of sea, would be steady ships, apart from bilge keel resistance.

In regard to the coefficient to be used for estimating the probable extinctive effect of bilge keels, it was decided after careful consideration to adhere to the late Mr. Froude's figure of 1.6 pounds per square foot for a mean velocity of 1 foot per second. This, as above explained, had been actually found by experiment to hold good in the *Sultan*, which was the only large ship that had been rolled having approximately similar form and period to those of the *Royal Sovereign* class. This action is shown to have been reasonable by the close correspondence since experimentally demonstrated between the curves of declining angles for the *Sultan* and *Revenge* without bilge keels (see Fig. 1).

We next proceeded to calculate the probable extinctive effect

due to bilge keels of about the dimensions which have since been added to the ships; assuming that the work due to fluid resistance on the bilge keels could be expressed by the formula used by the late Mr. Froude. Embodying the selected value of the coefficient of resistance, it was an easy matter to approximate to the probable additional loss of range per swing which the keels could effect, if the ship without the keels had reached a certain angle of oscillation under the influence of external forces. Taking an extreme case, and supposing the ship was rolling to 20 degrees on each side of the vertical, then this method of calculation showed that the addition of bilge keels 200 feet long and 3 feet deep would increase the extinction value by not quite 2 degrees (see Appendix, Note II).

It may be interesting to state, in passing, what would be the value of the coefficient for bilge keel resistance if the whole increase of work, shown by the experiments to result from the fitting of bilge keels, were credited to the bilge keel area. For an angle of swing of about 10 degrees, instead of the coefficient being 1.6 pounds per square foot of bilge keel area, it would be about 11 pounds. For a swing of 4 degrees (when the oscillation is nearly ceasing), the coefficient would reach as high a value as 15 to 16 as against 1.6. The details of the calculation appear in the Appendix, Note III.

It will be understood that these values of the coefficients for bilge keel resistance, deduced from the experimental data, are in no way put forward as truly representative of the actual resistance experienced per unit of area on the bilge keels. They simply represent, as before stated, what this coefficient would be if the assumptions held good—(1) that the whole of their work of extinction was equated to the area of the bilge keel; and (2) that their resistance varied as the square of the angular velocity.

The curves of extinction for the ship with bilge keels do not follow exactly, and throughout their whole length, the law which the late Mr. Froude laid down for such curves twenty years ago, viz:

$$-\frac{d\theta}{dn} = a\theta + b\theta^2.$$

But excluding very small oscillations of the ship, curves can be drawn (as shown in Fig. 3), whose equations obey this law, and which closely approximate to the experimental curves for values of θ from about 2 degrees to the largest angles obtained when the ship was rolling. The equations to these approximate curves, and to the corresponding curves without bilge keels, are given in the Appendix, Note I. From these equations it will be seen that (within the limits of swing for which the equation approximately fits the curve of extinction) the addition of bilge keels involves an enormous increase in those terms of the fluid resistance which vary as the *first power* of the velocity. This is indicated by the greater value of the a coefficient.

If the increase in the b coefficient (which is a measure of the work done by that portion of the resistance which varies as the square of the velocity) be assumed to represent the value of the bilge keel area coefficient, it will be found to be about 6 pounds per square foot, at one foot per second mean velocity, instead of 1.6 pounds. The details of the calculation appear in Note III of the Appendix.

Further investigation may, of course, show that this form of equation for curves of extinction will have to be definitely abandoned in some cases. But, as the matter at present stands, it would appear that the *Revenge* experiments point to a possibility which is also indicated by the results given by Mr. Froude in 1874. It appears that when bilge keels are added to a ship they must become effective, not merely as flat surfaces oscillating with the ship, and experiencing direct resistance, but by indirectly influencing the stream line motions which would exist about the oscillating ship if there were no bilge keels. It also seems possible that the existence of such keels as were fitted to the *Revenge*, even so deep below the surface (see Fig. 4), may be effective in producing a marked increase of surface disturbance, and so adding to the extinction. As pointed out long ago by the late Mr. Froude, a wave of insignificant dimensions, only a few inches in height, would be sufficient to account for all the work to be attributed to surface disturbance. Such waves might easily escape detec-

tion. For an estimate of the height of such a wave to fit the case of the *Revenge*, see Note IV in Appendix.

The facts obtained also suggest that for the very limited range and mean velocity of motion which is experienced by bilge keels, even when oscillating through arcs of 10 degrees or 12 degrees, the resistance upon them may vary, as Rankine and some other of the earlier writers supposed, as the first, and not as the second, power of the velocity. In such a case the curves of extinction, shown in Fig. 2, for the ship with keels would more nearly approach straight lines. For the *Revenge*, when performing a swing of 12 degrees, the bilge keels sweep through a distance of about 8½ feet in 8.4 seconds, with a mean velocity of about 1 foot per second.

INFLUENCE OF BILGE KEELS ON STEERING AND SPEED.

Independently of their steadying effect, the addition of bilge keels to the vessels of the *Royal Sovereign* class has had a sensible influence in another direction. These large ships have always had a good repute for handiness and steadiness in steering. Their tactical diameter without bilge keels was found to be about five times the water line length when both screws were going ahead, and about three and a half times with one screw reversed.

Reports from the ships state that since bilge keels have been added the tactical diameter has been reduced sensibly, and the steadiness in steering improved. Trials made with the *Revenge* after she was fitted with bilge keels gave a tactical diameter of 525 to 550 yards with both screws going ahead, or about four and a quarter times the water line length; and 350 yards with one screw reversed, or about two and three-quarter lengths. Similar trials in *Resolution* gave 500 yards as the tactical diameter with both screws ahead, and 300 yards with one screw reversed. These results are remarkable, and they completely dispose of the statements so often made, that large ships are necessarily unhandy and difficult to manœuvre.

As regards the influence of bilge keels on speed, the practical test of actual service proves that there is no sensible reduction

in speed for power, or material increase in coal expenditure for a given speed, at a given draught, and with the bottom in similar condition.

CONCLUSION.

The facts set forth in this paper, besides their value in regard to a large and important class of battleships in the Royal Navy, will be of service to Naval Architects generally when dealing with the extinctive effect of bilge keels in vessels of the largest size and longest period. The experiments made on the *Revenge*, with and without bilge keels, had been preceded, it is true, by others; and notably by those of the late Mr. Froude on the *Greyhound*, and of the French experimentalists mentioned above. Mr. Froude also worked out in the most thorough manner the method of model experiments on rolling, applying it especially to the cases of the *Devastation* and *Inflexible*.

APPENDIX.

NOTE I.

The differential equations to the curves of extinction, shown in Figs. 2 and 3, are as follows:—

C.–*Revenge*, light draught, no bilge keels $-\frac{d\theta}{dn} = .015\theta + .0028\theta^2$

D.– " deep " " " $-\frac{d\theta}{dn} = .0123\theta + .0025\theta^2$

A.–*Inconstant*, ... $-\frac{d\theta}{dn} = .035\theta + .0051\theta^2$

B.–*Sultan*, ... $-\frac{d\theta}{dn} = .0267\theta + .00166\theta^2$

For curves G and H in Fig. 3, which conserve the form—

$$-\frac{d\theta}{dn} = a\theta + b\theta^2$$

and which also approximate best to fit curves E and F in Figs. 2 and 3, for values of θ exceeding two degrees, the equations are:

G.—*Revenge*, light draught, with bilge keels $-\frac{d\theta}{dn} = .084\theta + .019\theta^2$

H.— " deep " " " $\frac{d\theta}{dn} = .065\theta + .017\theta^2$

In the text of the paper the extraordinarily large variations in the coefficients of the equations with and without bilge keels are discussed.

For the *Greyhound*, Mr. W. Froude obtained the following equations:—

	Period in Seconds.	Differential Equations.
Without bilge keels, . .	About 4.35	$-\frac{d\theta}{dn} = .044\,\theta + .0032\,\theta^2$
With bilge keels, . .	4.33	$-\frac{d\theta}{dn} = .035\,\theta + .05\,\theta^2$
" " " . .	3.88	$-\frac{d\theta}{dn} = .0198\,\theta + .0462\,\theta^2$

In this case the bilge keels were fitted for experimental purposes, and were of great proportionate depth and area for the size of the ship.

NOTE II.

Following the method of the late Mr. Froude (see "Naval Science," October, 1872), the relation between the decrement of roll (loss of range per swing) and the normal pressure on bilge keels of specified dimensions and given position on a ship is obtained thus:—

W = displacement of ship in pounds.
m = metacentric height in feet.
T = period of ship in seconds for a swing from out to out.
A = area of bilge keel in square feet.
r = mean effective radius in feet of the normal pressure on bilge keels from the axis of oscillation. (It will be sufficiently correct if, at any point in their length, the radius be measured from the mid-depth of keel to the middle line axis through the ship's center of gravity.)

C = coefficient of normal pressure in pounds per square foot of bilge keel area oscillating with a mean velocity of 1 foot per second.

θ = mean of the extreme angles of inclination from the vertical at the beginning and end of a swing.

$d\theta$ = extinction or angle from the vertical lost per swing.

If θ_n and θ_{n+1} be the angles of inclination from the vertical at the beginning and end of the n^{th} swing, then—

$$2\theta = \theta_n + \theta_{n+1}, \qquad \text{and } d\theta = \theta_n - \theta_{n+1}.$$

The work of resistance of bilge keels during any swing can only be done at the expense of an equivalent amount taken from the energy possessed by the ship at the commencement of that swing, and will be measured by the loss of dynamical stability during the swing.

Hence after integrating the resistance work function over, say, the n^{th} swing, and equating this to the corresponding loss of dynamical stability, we obtain for values of θ within limits for which the curve of stability is practically a straight line—

$$\frac{Wm}{2}(\theta_n^2 - \theta_{n+1}^2) = \frac{2}{3}\frac{\pi^2}{T^2} \cdot C A r^3 (\theta_n^3 + \theta_{n+1}^3)$$

which is approximately

$$Wm \,.\, \theta \,.\, d\theta = \frac{4}{3}\frac{\pi^2}{T} \cdot C A r^3 \theta^3. \qquad (1).$$

In estimating the loss of range per swing ($d\theta$) for the *Royal Sovereign* class, taking the ships under average conditions,

W = 32,000,000 pounds; m = 3.75 feet; T = 7.75 sections;

r = 40.5 feet; A = 1,170 square feet (both bilge keels),

we get by substitution in (1) above, on the assumption that C is = 1.6 pounds, for the case of $\theta = 20°$, or $\frac{\pi}{9}$ in circular measure.

$$d\theta = .0285, \text{ or } 1.63 \text{ degrees.}$$

Where greater accuracy is desired, and in most cases where the angle of inclination from the vertical exceeds 10° to 12°, it would be better to take the value of GZ obtained from the curve of stability in place of $m\theta$, and to measure the dynamical stability by the corresponding area of the curve of stability.

NOTE III.

To find the value of the coefficient for normal pressure on the bilge keels of the *Revenge*, on the assumption (*i*) that the whole of the observed increase in extinction value due to their addition may be credited to the work of their resistance whilst oscillating; (*ii*) that the resistance varies as the square of the mean velocity. The observed increase in extinction value will be measured by the ordinate intercept between curves *C* and *E*, or between *D* and *F*, according as ship is at her light or deep draught respectively.

Assumption (*ii*) implies that the bilge keel extinction value at any angle (θ) is a term with some b coefficient, say—

$$-d\theta = b_1\theta^2. \qquad (2).$$

Combining this with equation (1) of Note II, viz:

$$Wm \,.\, \theta \,.\, d\theta = \frac{4}{3}\frac{\pi^2}{T^2} \cdot C \,.\, A\, r^3\, \theta^3,$$

we get, on substitution of (2) in (1), and reduction, remembering that (2) is in degrees, and (1) in circular measure—

$$b_1 = \frac{\pi^3 \,.\, C\, A\, r^3}{135\ W \,.\, m \,.\, T^2}. \qquad (3).$$

Hence, if at any angle (θ) we take the ordinate intercept between, say, curves *C* and *E*, and divide it by θ^2, we shall get a b_1 value which may be substituted into (3).

An angle of swing of about 10° corresponds to an abscissa value of 5 in Fig. 2, where the intercept between curves *C* and *E* measures .62, and that between *D* and *F* .76. These divided by 25 (that is, θ^2) give a b_1 value of .0248 and .0304 respectively.

From the table of particulars given in the paper (page 5), we have for—

Revenge (deep), $W = 32{,}750{,}000$, $m = 3.86$, $T = 7.75$, and $r = 40.25$.

Revenge (light), $W = 29{,}950{,}000$, $m = 3.29$, $T = 8.4$, and $r = 41$.

For both conditions $A = 1{,}170$.

Substituting in equation (3), which may also be written—

$$C = \frac{135\ W \,.\, m \,.\, T^2 b_1}{\pi^3 A\, r^3} \qquad (4).$$

we get—

$C = 10.7$ (deep draught),
$C = 11.3$ (light draught).

If the intercepts for an abscissa value of 2 (that is, a swing of 4°) be similarly treated, the corresponding values of C will be found to be 15.3 and 16.4 respectively. For a swing of 14° its value will be rather less than 8.

Instead of crediting the *whole of the increased extinction value* to the bilge keel area coefficient, (*iii*) we may assume for purposes of calculation that the bilge keels are responsible only for that portion of the increased extinction represented by the excess in the value of b in the approximate equation to the curve of extinction for the ship with keels over the value of b in the equation of the corresponding curve of extinction for her with no keels.

In the equations for the *Revenge*, light draught, given in Note I, these b values are .019 and .0028—their difference, .0162. For *Revenge*, deep draught, they are .017 and .0025—their difference, .0145.

Substituting in formula (4) above, these values are found to be—

$C = 6.25$ (deep draught),
$C = 6.1$ (light draught).

These values are, of course, constant for all angles of swing between those limits within which the approximate equations to the curves of extinction are deemed sufficiently accurate.

With the first assumption made (viz: (*i*) above) this coefficient varied with the magnitude of the swing, and, within the range of the experiments, its value varied from less than 8 to about 16; with the second assumption (viz: (*iii*) above) its value was over 6, and constant up to about the largest angle reached in the ship.

It will be understood that these results are not given as even approximate values of the true coefficients for bilge keel resistance. They are derived from certain assumptions as to the values the coefficients must have, if the whole or part of the observed extinction were referred to the bilge keels.

NOTE IV.

In any estimate of the extent of wave making disturbance produced by an oscillating ship, we must equate the work of that portion of her extinction value (or loss of range per swing), which varies as the single power of the velocity, to half the total energy of the two half waves (*i. e.*, one on each side created at the surface each swing. The wave system maintained only travels at half the speed of the individual waves, the ship has therefore only to supply energy for half a wave per swing.

In this case—

$$-d\theta = a\theta.$$

The work due to loss of range per swing, as in Note II —

$$= W \,.\, m \,.\, \theta \,.\, d\theta \text{ foot pounds}$$

becomes, therefore—

$$Wma\theta^2 \text{ foot pounds.}$$

Following the method of the late Mr. Froude (see *Naval Science*, July, 1874) let—

h = height in feet from hollow to crest of wave created.

l = its length in feet, from crest to crest.

s = its width in feet along the crest. This must approximately equal the length of the ship.

The total energy of a complete wave $= 16\,lsh^2$ approximately.

Hence, we must have—

$$Wma\theta^2 = 8\,lsh^2, \tag{5}$$

to fulfil the conditions stated above.

The length of a wave is approximately $5\frac{1}{8}$ times the square of its period, and since the waves are created by swings of the ship, they will be co-periodic—that is, the period of the wave will be identical with the period of the ship for a double swing from out to out and back again. Hence—

$$l = 20.5\ \mathrm{T}^2.$$

substituting in (5), we get $Wma\theta^2 = 164\,h^2 s\mathrm{T}^2$.

that is

$$h = \frac{\theta}{T}\sqrt{\frac{Wma}{164s}} \tag{6}.$$

From the particulars for the *Revenge*, say, at deep draught, given above, we have

$$\frac{m}{s} = \frac{1}{100} \text{ approximately.}$$

$T = 7.75$. $W = 32{,}750{,}000$. $a = .0123$ (no bilge keels).
$a = .065$ (with bilge keels).
Substituting in (6), we get— $h = .64\,\theta$ (no keels).
$h = 1.48\,\theta$ (with keels).

In the *Revenge* experiments with no keels, the greatest angle from the vertical reached was about 13 degrees, that is, $\theta = \frac{9}{40}$ in circular measure; with keels the angle was about $5\frac{3}{4}$ degrees, that is, $\theta = \frac{1}{10}$. These give $h = .145$ (no keels), or .148 with keels. For the *Revenge* at light draught the corresponding values of h are .135 and .138.

We thus see that a wave less than 2 inches in height will account for the whole of the surface disturbance indicated, even at the greatest angles reached, by the experiments with the *Revenge*, either with or without bilge keels.

The "shoring ribbands" on the sides of the ship, entering and leaving the water with each swing, caused some surface disturbance which would have certainly masked, and so interfered with the detection of these small waves, less than 2 inches in height, as we see, even if it had been otherwise possible to observe them in open tidal waters. The immersion and emersion of the shoring ribbands, no doubt, caused some increase of fluid resistance to rolling. Whatever the extinctive value due to them may have been, these ribbands were operative throughout all the experiments.

Fig. 1.

CURVES OF DECLINING ANGLES

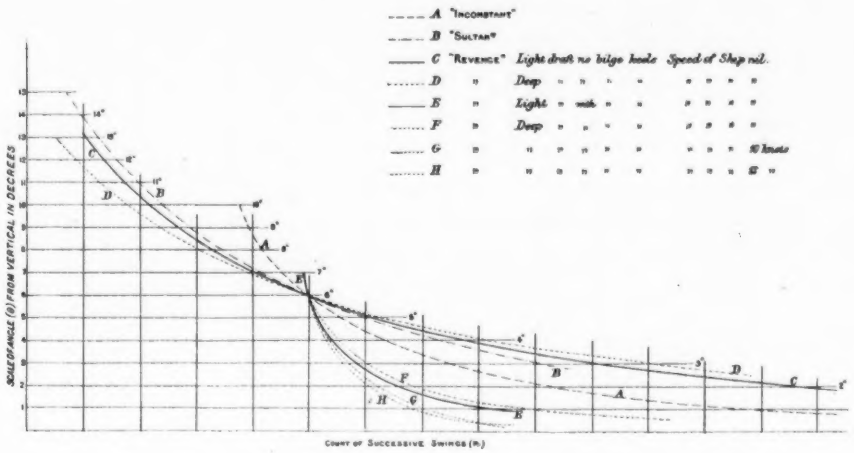

A "Inconstant"
B "Sultan"
C "Revenge" Light draft no bilge keels Speed of Ship nil.
D " Deep " " " " " " "
E " Light " with " " " " "
F " Deep " " " " " " "
G " " " " " " " 10 knots
H " " " " " " " 12 "
SEMI-RANGE (θ) FROM VERTICAL IN DEGREES
COUNT OF SUCCESSIVE SWINGS (n.)

FIG. 2.

CURVES OF EXTINCTION

A "INCONSTANT"
B "SULTAN"
C "REVENGE" Light draft no bilge keels Speed of Ship nil.
D " Deep " " " "
E " Light " with " " " " "
F " Deep " " " " " " "
G " " " " " " Dimmies
H " " " " " " " " "

Probable extension beyond range of experiments shown thus .....

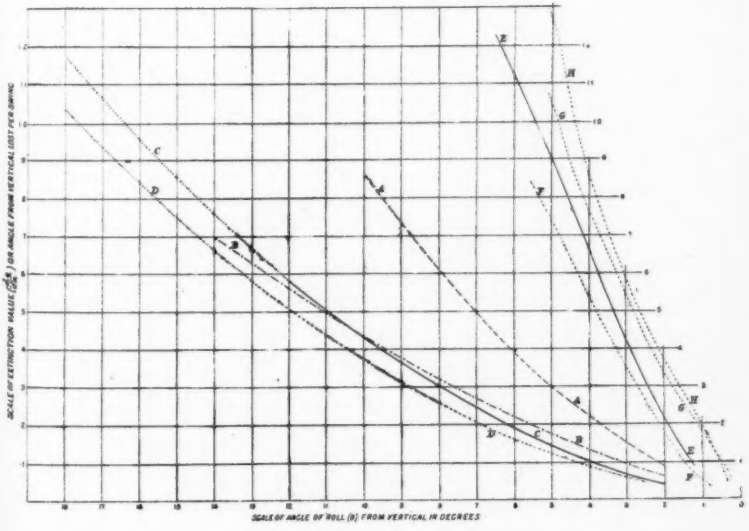


FIG. 3.

CURVES OF EXTINCTION FOR "REVENGE"

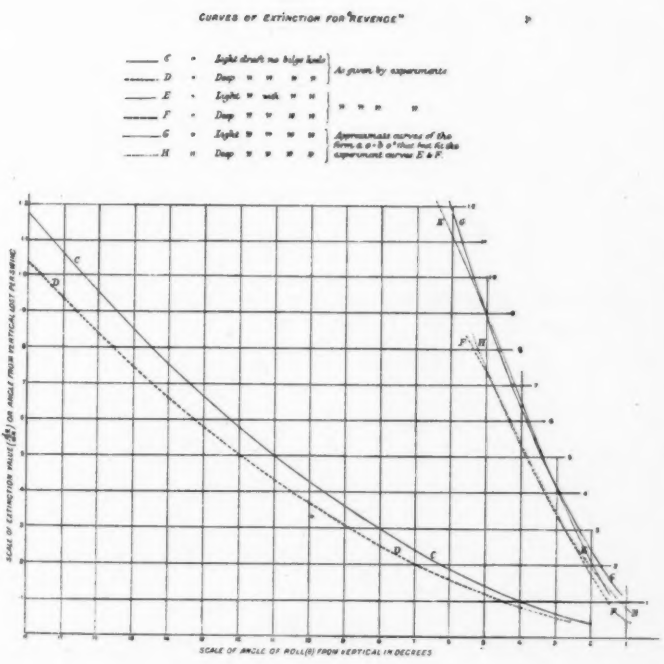
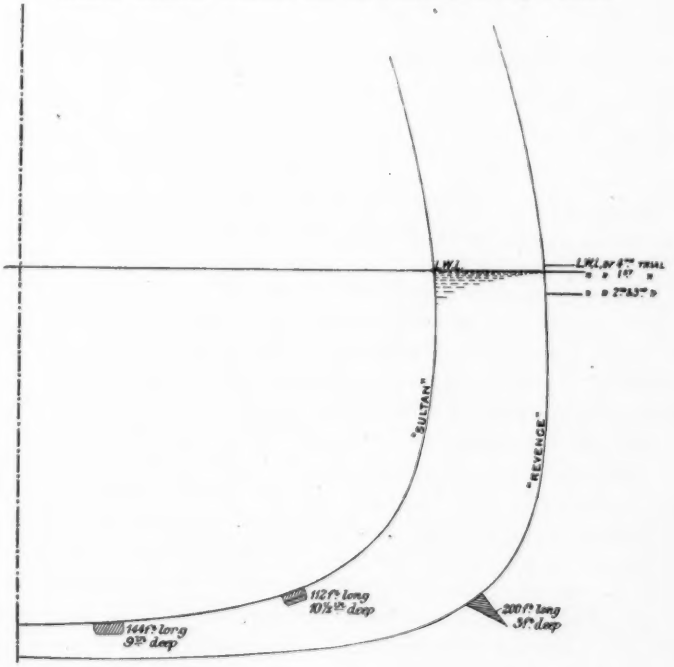

C = Light draft no bilge keels
D = Deep " " " " } As given by experiments
E = Light " with " "
F = Deep " " " " } " " " "
G = Light " " " " } Approximate curves of the form a a+b a° that best fit the
H = Deep " " " " } experiment curves E & F.
SCALE OF EXTINCTION VALUE ($\frac{GM}{BM}$) OR ANGLE FROM VERTICAL WET PLASHING
SCALE OF ANGLE OF ROLL(θ) FROM VERTICAL IN DEGREES

Fig. 4.

MIDSHIP SECTIONS, SHOWING SIZE AND POSITIONS OF BILGE KEELS.



NEW REVENUE CUTTERS.

By First Assistant Engineer Chas. A. McAllister,
U. S. R. C. S.

On June 26th bids were opened at the Treasury Department for the construction of two first class revenue cutters, one for service on the Great Lakes, to be stationed at Milwaukee, Wis., and the other for service on the New England coast, to be stationed at Boston, Mass. The contract for the construction of the Milwaukee cutter has been awarded to the Globe Iron Works of Cleveland, Ohio, at their estimate of $148,700, and the Boston cutter will be built by the Atlantic Works of East Boston, for $159,951. The general dimensions of both boats are: Length over all, 205 feet; length between perpendiculars, 188 feet; breadth of beam molded, 32 feet; depth of hold amidships, 17 feet. The Milwaukee cutter will have a displacement, at a mean draught of 10 feet 9¾ inches, of 906 tons; the Boston cutter will displace 980 tons at a mean draught of 12 feet 3 inches. The general design is practically the same for both boats, with the exceptions that the Boston cutter is of composite build and brigantine rigged, whereas the Lake vessel will be built entirely of steel and schooner rigged. It may be noted that the new Boston cutter will be the first modern vessel for this Government to be of composite build. The following are some of the details of her construction: In addition to the flat keel plate, of 20 pounds per square foot, there will be a main wooden keel of yellow pine or Oregon fir sided, 14 inches by 14¼ inches in depth, the lower edge of the rabbet for the garboard strake being 7 inches above

the bottom of keel; there will also be a false keel of white oak, 14 inches in width and 3 inches thick, fastened to the main keel by 6-inch composition spikes. The lower parts of the stem, stern post, rudder post and the rudder frame will be of manganese bronze. The upper parts of the stem, stern and rudder posts will be of the best hammered iron, and scarphed and riveted to the lower parts of the same. The planking will extend from the keel to about two feet above the load water line, amidships. It will be of the best quality of yellow pine or Oregon fir, and will have a thickness, with the exception of the garboard strake, of 5 inches. At the keel the garboard strakes will be $7\frac{1}{2}$ inches thick, tapering to 5 inches at the outer edge. The upper edge of the top strake will be protected by a beveled angle bar, 3 by 3 inches, of 7 pounds per foot, worked from stem to stern and calked water tight to the outside plating. The fastenings will be of bronze bolts and nuts, $\frac{15}{16}$ inch diameter at the shank. The heads of the bolts will be let into the planking about $\frac{7}{8}$ of an inch, the recess over the heads to be filled either by plugs or Portland cement. The steel plating for both vessels will be of the best quality of mild open hearth steel, the requirements for which are that it shall have a tensile strength of not less than 55,000 pounds per square inch, and an elongation, in a length of 8 inches, of not less than 25 per centum.

With the exception of a small forecastle deck, both vessels will be flush decked; the captain's and officers' quarters will be located aft, on the berth deck, and will be roomy, and fitted up with all conveniences. The petty officers' and crew's quarters will be forward. In the house on the main deck will be the ship's galley, officer's lavatory, executive officer's office, engineer's workshop, boatswain's locker and lamp room. The pilot house and chart room will be located on top of the main house.

Through the stem of each vessel there will be a 15-inch torpedo tube, to be used for launching torpedoes, in case these revenue cutters should be used as auxiliaries to the Navy in time of war. Their regular armament will consist of one 6-pounder rapid fire gun mounted on the forecastle deck, and two 1-pounders mounted on the rail just abaft the mainmast. Each cutter

will carry four boats, including a 30-foot steam launch. It is expected that the new vessels will be able to maintain a cruising speed of 16 knots an hour; for short runs, they will, no doubt, make as high as 17½ knots. There is no contract requirement for speed, and consequently no premiums will be awarded. The specifications require that the engines shall be able to make a successful run of at least eight consecutive hours, working off at 160 pounds pressure all the steam the boilers will make with clean fires, using free steaming coal, to be selected by the superintending engineer.

The propelling machinery for these vessels will be of the same design, with the exception of the manner of securing the sea and injection valves to the hull. Although the lake vessel will be in fresh water, the possibility of her being transferred to the coast at some future date, has caused every appliance, such as surface condenser, distilling apparatus, zinc protection, etc., to be specified for her machinery. The total indicated horse power of the main engine, air and circulating pump engines will be about 2,000, when the main engine is making about 160 revolutions per minute. There will be one vertical, inverted cylinder, direct acting triple expansion engine, with a high pressure cylinder, 25 inches, an intermediate pressure cylinder, 37½ inches, and a low pressure cylinder, 56¼ inches in diameter, with a common stroke of 30 inches. The high pressure cylinder will be forward and be fitted with a piston valve; the intermediate and low pressure cylinders will each be fitted with a double ported slide valve. The framing of the engine will consist of three wrought steel columns at the front, each 6 inches in diameter, and three cast iron columns at the back, the latter forming a part of the three sections of the main condenser. The valve gear will be of the Stephenson type, with double bar links; the intermediate eccentrics will be worked on the coupling of the two sections of crank shaft. The engine bed plate will be of cast iron, in one section, and be supported on a foundation built up from the frames of the ship; a feature of this foundation is that it will be extended aft under the thrust bearing, the top plate of the foundation being ¾-inch steel plate. In addition to this, the thrust bearing will be secured to

the bed plate by means of lugs cast on the same. The crank shaft will be 10½ inches in diameter, forged solid and in two sections. All the shafting, as well as the piston rods, connecting rods, eccentric rods, valve stems and reversing shaft will be of the best mild open hearth steel. The main condenser will be cast in three sections, securely bolted together and forming a part of the framing of the engine. The total cooling surface will be about 3,000 square feet, measured on the outside of the tubes. The tubes will be 1,253 in number, ⅝-inch outside diameter, No. 18 B.W.G. in thickness, and 14 feet 5 inches long between tube sheets. There will be one vertical, independent, single acting, twin air pump worked by two steam cylinders. The diameter of the steam cylinders will be 9 inches, of the pump cylinders 20 inches, and a common stroke of 12 inches. The pump cylinders will be of cast iron with composition linings. The circulating pump will be independent, and of the centrifugal type, having a discharge nozzle 10 inches in diameter. The pump will be driven by a vertical engine, 8 inches in diameter and 8 inches stroke. The main and auxiliary feed pumps will be of the vertical duplex type, having steam cylinders, 8 inches in diameter, water cylinders, 5 inches in diameter, and a stroke of 12 inches. The water ends of these pumps will be entirely of composition, Naval standard, and be provided with water pistons of composition. A special fire pump will be provided, of the vertical duplex type, having steam cylinders 14 inches in diameter, water cylinders 8½ inches in diameter, and a stroke of 12 inches. There will be a complete distilling apparatus, capable of producing 3,500 gallons of potable water every twenty-four hours.

The propeller will be four bladed and of maganese bronze. The engineer's workshop will be on the main deck and will be equipped with a lathe, planer, drill press and shaper; all to be run by an independent engine. The electric light plant will be located in the upper engine room and will be complete in every detail. The dynamo will be of 10 kilowatts capacity, working at 80 volts. The engine will connect direct to the dynamo and make about 500 revolutions per minute. There will be 140 fixed lights of 16 candle power each in the various compartments of the vessel.

A powerful search light will be erected on top of, and be controlled by a hand wheel within the pilot house.

Steam will be supplied by four single ended boilers of the horizontal, return fire tube type. Each will be 11 feet 6 inches, outside diameter, and 10 feet long over all. The total heating surface will be about 5,200 square feet, and the total grate surface, 168 square feet; each boiler will have two corrugated furnaces, 42 inches internal diameter. The shell of each of these boilers will consist of two plates only. Each plate of the shell will be about 18 feet long and 9 feet 6 inches wide. Although it will take nearly a 10,000 pound ingot for each plate, no trouble has been found in placing the orders for this material. All plates used in the construction of the boiler will be of the best mild open hearth steel. Longitudinal specimens cut from the shell plates must show a tensile strength between 58,000 and 67,000 pounds per square inch and an elongation in a length of 8 inches, of not less than 25 per cent. The elastic limit shall in no case be less than 29,000 pounds per square inch. The tensile strength of furnace and flange plates must be not less than 50,000, nor greater than 60,000 per square inch, and the elongation in a length of 8 inches not less than 28 per cent. The boiler tubes will be of the best charcoal iron, $2\frac{1}{2}$ inches in external diameter. The ordinary tubes will be No. 10 B.W.G. in thickness, and the stay tubes No. 6 B.W.G. There will be one athwart ship fireroom. The uptakes from the four boilers will unite to form the base of the smoke stack, which will be double and 6 feet 9 inches in external diameter. The closed fire room system of forced draft will be used and arrangements will be made to make the fire room as nearly air tight as possible. There will be two fire room blowers of the Sturtevant type, provided with air ducts from the two 19-inch ventilators and discharging directly into the fire room.

In addition to the above cutters, plans and specifications are now being prepared for a cruising cutter intended for use on the Pacific Coast at a cost not to exceed $200,000, and a small cutter for use in San Francisco harbor, at a cost not to exceed $50,000. The Pacific Coast cutter will be about 220 feet long over all, 200

feet long on the water line, 32 feet 10 inches extreme beam, 12 feet 3 inches mean draught, and have a displacement of about 1,000 tons. She will be a single screw vessel, having a triple expansion engine capable of developing 2,000 horse power. The San Francisco boat will be 110 feet long, and have a triple expansion engine capable of developing about 500 horse power. There are also in construction for this service the revenue cutter, *Windom*, for the Baltimore station, the steam launch, *Tybee*, for Savannah harbor, and two 65-foot launches for service in Puget Sound.

NOTES.

THE RUN OF THE *COLUMBIA*.

In order to test the ability of the *Columbia* to maintain high speed along the trade route of the North Atlantic, the Navy Department ordered that, after being docked at Southampton and having her bottom cleaned, she proceed to New York under all boilers and her three engines, using natural draft except during the last 24 hours, when mild forced draft was to be used. Her departure from Southampton was somewhat delayed on account of slight straining she received when docked, the report on which will be found at the end of this account.

She left Southampton at 12·30 P. M. on Friday, July 26, passed the Needles at 2 P. M., and arrived at Sandy Hook at 8·59 A. M. on Friday, August 2, having made the run of 3,090 miles in 6 days 23 hours and 49 minutes, or at an average rate of 18.41 knots.

The daily runs were 405, 460, 462, 450, 455, 453 and 405 miles to Sandy Hook lightship.

The entire run was made under natural draft, as it was found impracticable on the last day to transport coal from the distant bunkers rapidly enough to supply the furnaces. The coal burned was limited to 200 tons during the first two days, and to 225 for the four succeeding days. The total amount burned was 1,475 tons, or at the rate of 212 tons a day for all purposes. The auxiliaries consumed about 11.33 tons per day.

When she started, the *Columbia* drew 26 feet 3 inches forward and 25 feet 6 inches aft, with the after trimming tanks full, thus being down by the head, from which cause she shipped considerable water from time to time. On her arrival at New York, the draught was 20 feet 10 inches forward and 24 feet 4 inches aft.

The mean draught for the run was, then, 23 feet 14¾ inches, corresponding to a displacement of about 8,152 tons. The displacement on her acceptance trial was 7,350 tons.

The weather was generally fair, with westerly winds, except on the 30th of July, when it became necessary to slow down for four hours on account of fog and heavy weather.

The following is a brief summary of the log for the several days of the run:

Friday, July 26.—Passed the Needles at 2 P. M., and the Lizard at 9.50 P. M.; making from 18 to 19 knots in the Channel. Light westerly wind.

Saturday, July 27.—Moderate sea; light to fresh northerly wind. Distance run to noon, 405 miles. Coal, 196.25 tons. Average revolutions of engines: Starboard, 97.2; port, 97.3; center, 96.6. Leaky tubes in one boiler rendered that boiler useless for seven hours.

Sunday, July 28.—Gentle breezes, smooth sea. Distance run, 460 miles. Coal, 201.25 tons. Average revolutions: Starboard, 104.1; port, 103.9; center, 103.7.

Monday, July 29.—Smooth sea, fresh S.S.W. wind. Distance run to noon, 462 miles. Coal, 225.50 tons. Average revolutions: Starboard, 105.8; port, 105.8; center, 105.7.

Tuesday, July 30.—Fresh breeze from W. by S. Distance run to noon, 450 miles. Coal, 229.75 tons. Average revolutions: Starboard, 103.2; port, 103.3; center, 102.6; Slowed for four hours on account of fog and heavy sea.

Wednesday, July 31.—Fresh breeze from W.S.W. Distance run to noon, 455 miles. Coal, 230 tons. Average revolutions: Starboard, 105.9; port, 105.9; center, 105.1.

Thursday, August 1.—Fresh breeze from W.S.W. Distance run to noon, 453 miles. Coal, 230 tons. Average revolutions: Starboard, 105; port, 104.9; center, 104.4.

Friday, August 2.—Passed Sandy Hook lightship at 8.59 A. M. Distance run since preceding noon, 405 miles. Coal burned to 9 A. M., 221 tons. Coal on hand at noon, 328 tons.

From the Needles, England, to Sandy Hook, N. Y.—

	1	2	3	4	5	6	7
Distance run	405	460	462	450	455	453	405
Coal burned for steaming purposes, tons	168.9	189.9	214.7	218.5	218.6	218.6	211.1
Steam pressure at boilers	140	134	131	128	135	133	128
Revolutions—Starboard	97.2	104.1	105.8	103.2	105.9	105	104.4
Port	97.3	103.9	105.8	103.3	105.9	104.9	104.4
Center	96.6	103.7	105.7	102.6	105.1	104.4	102.3

This run of the *Columbia* must be considered a remarkable one for a man-of-war, and demonstrates that the two vessels of this class are capable of maintaining, under natural draft, over long distances at sea, a speed inferior only to that of a few of the "ocean greyhounds," and almost equal to that of vessels of her class in foreign navies on their forced draft trials.

The maximum speed for any one hour of the run was 20.6 knots, and for four hours, 80.5 miles.

It will be of interest to compare this run with the *best* runs of the transatlantic steamers going over the same course.

	D.	H.	M.
Fürst Bismarck	6	10	32
Normannia	6	12	30
Paris	6	16	43
New York	6	17	14
Augusta Victoria	6	20	22
St. Louis	6	18	47
U. S. S. *Columbia*	6	23	49

The time of the first trip of the *St. Louis* was 7 days 7 hours and 11 minutes.

Extract from the report of the Board appointed to examine the hull of the *Columbia*:

"In general, the actual damage is slight, it being confined to loose and leaky rivets and a few leaky butts and seams in the flat keel plates and to dents in the flat keel plates and garboards. These dents occur evidently where the ship rested on the keel blocks at Southampton, and are all located at the outer edges of it on the flat keel plate and in the seam of the keel plates and garboard, or at an average of 17 inches from the vertical keel.

The starboard side has suffered markedly more than the port. The damage to the keel and garboard is greatest at the fore end, just abaft the buckle, where the keel begins to cut up, and noticeably decrease aft, until all damage, even to the cement, disappears forward of the engine room. Forward of the knuckle nothing has been injured. Five of the seven long stanchions in the fire room, reaching from the protective deck to the inner bottom, are buckled, the worst having a permanent set of 1½ inches. No plates or angles are cracked. Four rivets are sheared sharp off, which secure a floor bracket to the frame bar within the double bottom.

"Two brackets, two floor plates, two water tight floors and the vertical keel are buckled, none of them seriously. We find no damage to the machinery has been sustained.

"We find that the cause of the damage and injury sustained by the hull of the *Columbia* by the docking at Southampton was generally careless and unskillful docking, as shown by apparent neglect of most elementary precautions to secure the uniform support of the keel of the ship. The immediate cause of the dents and bruises to the bottom plating of the *Columbia* was that the keel blocks in Southampton were not properly aligned, and did not bear equally, and that each block was not squared off to give support to the flat and level surface of the flat keel. On the contrary, the keel blocks had been repeatedly used, and by bar keel vessels, so that they were crushed down in the center to such an extent that, when examined, as soon as the water was out of the dock at Southampton, a considerable number showed no bearing whatever on the flat part of the keel, and only bore on the outer edges on the bottom plating. Wedges were driven between the keel and the center of these blocks at the request of the officers of the *Columbia*. A vessel was floated out of the Southampton dock just before the *Columbia* was taken in.

"A serious contributory cause to the damage was that the keel blocks were not built up forward, where the forefoot is cut away from a point 107 feet abaft the forward perpendicular. This very considerable proportion of the length of the ship was left

entirely unsupported, and was only shored up some time after the dock was pumped out, at the request of the officers of the ship, an ineffectual method of taking the weight, if promptly and properly done. No bilge blocks were used, and the bilge shores were only put in when requested.

"The following repairs are recommended:

"Loose rivets to be cut out and redriven, leaky butts and seams to be caulked and reriveted where necessary, bent bracket frames to be straightened and reriveted, broken and cracked cement to be replaced. The estimated cost for this labor is $475, and the material $50; a total of $525, and the total time required, twelve days.

"It will be noted that the fire room stanchions showed slight increase in buckling after the ship was docked on the 12th instant, although the ship rested equally on fair, true blocks, built up forward to a point 46 feet from the forward perpendicular, therefore we recommend that these stanchions be renewed when opportunity occurs after the ship is afloat. Estimated cost of six new stanchions is: Labor, $275; material, $200; time required, eight days."

U. S. S. *NEW YORK*.

The following table gives the results of the recent run of this vessel from Southampton, England, to New York:

Date	May 18–28, 1895.
Running time, hours *	242.42
Average revolutions of engines, per minute	78.60
steam pressure, at boilers, in pounds per square inch	144.3
vacuum, in inches of mercury	24.72
revolutions, double strokes, of air pump	17.47
coal burned, in pounds per hour, for steaming purposes	7,170
speed, in knots, by patent log	13.77
indicated horse power, including air and circulating pumps	2,991
displacement, in tons	8,550
Propellers: Diameter, 16 feet; mean pitch, 21 feet; total helicoidal area of one propeller, 69.093 square feet.	
Number of engines in use during run	2

* For 22 minutes of this time the engines were backing.

THE ACCIDENT TO THE TORPEDO BOAT *ERICSSON*.

The following notes were prepared by Assistant Engineer Edw. L. Beach, U. S. N., Inspector of Machinery for the *Ericsson*.

It will be recalled that during a trial run in 1894, a dowel pin of the starboard low pressure piston rod, connecting piston and rod, worked loose and fell to the bottom of the cylinder. At the next stroke of the engine the piston rod broke at the lower face of the piston, the latter being then thrown up with great force, breaking the top of the cylinder, also the low pressure steam chest, which is part of the same casting as the second intermediate cylinder. No one was injured at this time.

New cylinders were cast by the builders, and one new piston rod was made. When fitting up the new machinery, the piston rod which had been in use in the port low pressure engine was placed in the starboard engine. The superintendent of the works informed the writer that this was done because it would be easier to fit. This is to be remembered, as it had a most important bearing upon the disastrous catastrophe.

For the trials held in 1895 the builders of the *Ericsson* secured the services of Mr. Geo. F. Coleman (as chief engineer), who is well known in connection with the trials of the *Maine*, and is also under contract to run the trials of the *Texas*. Mr. Coleman was empowered to hire what men he chose, and he was able to get experienced men as his assistants. The machinery and pipes were all re-erected under his supervision, and, after numerous preliminary contractors' trials, it was decided, July 17, to make a full power speed trial preparatory to running over the trial course which had been laid out. The boat left its dock at about 8·45 A. M., July 17, ran between the two lightships outside of New London, Conn., turned around and started to run back. She passed the second lightship, and about eight minutes later was enveloped in a cloud of steam, and the men came tumbling up out of the engine room. The main stop valves on deck were immediately shut, the safety valves of the boilers being opened at the same time; this necessarily occupied an appreciable length of time. At the same moment the boat gave a wide sheer to starboard, showing that the starboard engines were stopped. There

were five men at the time in the forward part of the engine room attending to the main engine, and three in the after part at the air and feed pumps. These last three were able to get out without burns, save a few trifling scalds on the hands and face of one. The five men in the forward part all succeeded in getting out through the hatch over the condenser. They were all frightfully scalded.

Records taken a moment before the accident showed the engines to be making about 400 revolutions a minute. Steam pressures were as follows: Boiler, 240 and rising; first intermediate receiver, 115; second intermediate receiver, 55; low pressure receiver, 20. Vacuum, 27 inches.

After the engine room was cool enough to enter, it was discovered that the upper part of the starboard low pressure cylinder and steam chest was broken and thrown up a distance of 2 or 3 inches.

A pass-over steam pipe connects the main steam pipe with the low pressure steam chest, and this pipe was carried up by the broken part of the steam chest. This pass-over pipe broke *inside of its valve* just where it is connected by an elbow and nipple to the main steam pipe, the elbow of cast steel, standard, 1½ inches, breaking in its turn, and thus allowing boiler steam to pass from the main steam pipe through the nipple and broken elbow into the open space of the engine room. The elbow was situated a little to port of the middle of the part of the engine room forward of the condenser. As soon as possible the nipple was removed from this main steam pipe, the hole plugged up, and the boat started to return with the port engine running with steam from one boiler only; soon the condenser became hot, as did also the engine room, and it was observed that the exhaust steam from the port low pressure cylinder passed to the top of the condenser, then up through the starboard exhaust pipe to the broken cylinder, and from there to the engine room space. It was necessary to stop the port engine, take down the starboard exhaust pipe, and blank the joint on the condenser; when this was all done the *Ericsson* proceeded on her way with the port engine, running to the dock at New London. No valves are fitted to these exhaust pipes because of the extra weight involved.

On the next day the broken parts of the machinery were taken out. Examination showed the cylinder and steam chest to be broken below the flange, the piston before taken out being cock billed in the cylinder. The piston rod was broken at the lower face of the piston. The low pressure valve was cracked, and the piston, cylinder head and low pressure valve stem were ruined. All these parts must be replaced by new ones. The surfaces of piston and cylinder were absolutely free from any indentation, showing that no foreign piece of metal had got in to cause the break. It has been stated that this piston rod had previously been used in the port low pressure cylinder at the time of the previous accident. At that time the rod was bent and strained and badly distressed about 1 inch below the piston, probably up to, if not beyond, its elastic limit. This rod was then straightened, which further distressed it, and after regrinding, it was placed in the starboard low pressure engine for use. It is believed that the cause of the break was the using of this rod by the contractors, instead of fitting a new one, as should have been done. The strength of the rod itself was ample for all direct loads that could have been put on it, it being of forged steel, $2\frac{1}{8}$ inches in diameter. The broken metal of the cylinder castings gave a combined area of about 112 square inches. If this cast iron had a tensile strength of 20,000 pounds to the square inch, the blow that broke this must have had a striking force of 2,240,000 pounds, or 1,000 tons.

The piston itself was rather loose in the cylinder, there being a play of between $\frac{1}{64}$ inch and $\frac{1}{32}$ inch all around; the fact that the piston was found in a cock billed position shows that it was not tight. The piston itself, though unquestionably strong enough, appears frail and light to one conversant with ordinary engines. When running at the high piston speed of 1,100 feet per minute, with a pressure of 20 pounds per square inch on one side and a vacuum of 27 inches on the other, the piston must have had a movement of its own which might be likened, though greatly exaggerated, to the opening and the shutting of an umbrella. Now, the piston being loose on its sides, and having some play of its own, would it not have a bending effect upon

the piston rod? And, after a great number of strokes, might not the strength of the rod be seriously impaired, so that it would unexpectedly break at the ordinary working load?

Again, this cylinder works under conditions entirely dissimilar to the low pressure cylinder of engines generally. At high speeds the latter will make perhaps two double strokes to the second, whereas the *Ericsson* piston will make seven double strokes to the second, so that there will be much more frequent and violent changes of temperature in the low pressure cylinder of the *Ericsson* than in the others. It is to be hoped that the remains of the piston rod will be put in a testing machine, and its strength tested at different parts.

A comparison of the *Cushing* with the *Ericsson* may be of value. The *Cushing* has five cylinder, quadruple expansion engines, there being two low pressure cylinders, each 22½ inches in diameter. The piston rods in this case are 2 inches in diameter. The engines work at the same steam pressure. The combined area of the *Cushing's* low pressure cylinders for one engine is about 800 square inches, and that of the *Ericsson* 707 square inches. The combined area of the *Cushing's* corresponding two piston rods is 6.28 square inches, which for one rod would be equal to a diameter of 2.8 inches. The *Ericsson* has only one rod 2⅛ inches in diameter, the work done in the cylinder being nearly the same.

If the piston has any motion of its own in the cylinder, stiffness and rigidity are much in favor of the *Cushing's* engines, for on the *Ericsson* is the piston of 30 inches in diameter, of nearly double the area, and doing twice the work, with a diameter of piston rod of 2⅛ inches, to the 2-inches diameter rod of the *Cushing* in a 22½-inches cylinder. If there is any such working on the piston rod, due to the spring and motion of the piston, it would be much greater in the case of the *Ericsson*, because this may be said to be a couple in which the arm or lever is longer, and the power applied greater, to withstand which it has a rod only ⅛ inch greater in diameter, or .4 square inch more in area.

Some thoughts have arisen in the mind of the writer, caused by being a witness of the late catastrophe on the *Ericsson*, which

are impressed so strongly upon him that he deems them worthy of consideration by those who are to design the torpedo boats which will in time form a very important branch of our Navy.

To begin with, the pipe that was broken was not in the design of the *Ericsson's* machinery, as first sent out by the Bureau of Steam Engineering, and was only allowed after special request by the contractors. This is the first point to note about this pipe; the second point, and one which should never be forgotten, is that this pipe was absolutely never used while the boat was underway. The lesson to be drawn from this is to avoid pipes to be used for remote contingencies; far better to imagine they are remote to occur; get along with one pipe for many services, and avoid many pipes for one service.

2d. As soon as the accident was made apparent the closing of the main stop valves was immediately commenced on deck; during the time this went on, boiler steam was pouring into the engine room. Had there been fitted an automatic valve, which would have immediately shut off steam from the boiler rooms, there need not have been a death resulting, nor anything but trifling scalds. Or, if such an automatic valve could not be depended on in every case, a man might be stationed on deck during trials, who, on the first sign of an accident, could throw down a lever, which would shut a butterfly valve situated in the correct position in the main steam pipe. If one or the other of these plans is adopted, it ought to be conducive to life saving in the future.

3d. A closed engine room will confine steam let loose in it, carrying death and destruction with it. There should be a hatch, open over the whole length of the engine room, the necessary structural strength being given by beams athwartship. A cover could be designed to such a hatch, to be carried always, and to be securely fastened by bolts when the boat is going to sea for ordinary cruising, and which could be left off when on trial trips or running at great speeds for short distances. At the time of the accident to the *Ericsson* the forward middle plate of the engine room had been left off, size 4 feet 8 inches by 2 feet 10 inches.

A great quantity of steam came out of this opening and the two small hatches aft of this. All the steam pipes are at the top of the engine room, just under the deck. Had there been such an open hatch over the *Ericsson's* engine room the steam would not have been confined, and there is reason to believe no lives would have been lost.

4th. Although only an inch and a half steam pipe broke, allowing steam at a pressure of 250 pounds to the square inch to escape into a comparatively small and confined space, in which at the time were five men, yet each of these men was successful in getting out of the engine room, though they had to climb over the circulating pump to the top of the condenser, and thence up a vertical ladder to the deck. In doing this they fell over each other and impeded each other in getting out. With an open hatch, and ladders more conveniently placed, this might not have occurred. The last man out, Strinskey, conceived it his duty to stop the starboard engine before he left. This he did, and this extra delay in all probability caused his death.

The point to be remembered is that all five men got out. The second and third men out both died, not from their scalds and burns, but from the inhalation of steam. The fourth man out was the most seriously scalded, and is now considered out of danger, because, as he informed the writer, he "had sense enough not to breathe steam."

At either end of the engine room are boiler rooms filled with compressed air. Suppose the man stationed on deck, in case of a broken steam pipe, had another connection to his lever so that the latter would not only jam shut the butterfly valve on his end of the engine room, but would also uncover an opening through the lower part of the fire room bulkhead. Would not the lower part of the engine room then become filled with fresh air, and the steam forced up through the open engine room hatches? With such an arrangement the men below, having air to breathe instead of steam, would have much more of a chance for life.

One more point: All engineers will agree that frequent examination is vital to the safety and good care of machinery. For reasons patent to all, this will apply much more to torpedo boat

machinery than to ordinary man-of-war engines. And yet the *Ericsson* is so constructed that it will be impossible to examine her cylinders except by taking down about all the steam piping there is in the engine room. There is no good reason why holes over the cylinders should not be cut in the deck overhead, and plates fitted to be securely bolted over these holes. By these means, the engineer would be enabled to examine the machinery under his charge, and would have that confidence which must necessarily be lacking under the present conditions.

RECORD OF AN EXPERIMENT TO DETERMINE THE EVAPORATIVE EFFICIENCY OF A BRAND OF FRENCH BRIQUETTES.

The following record was transmitted by Past Assistant Engineer Howard Gage, U. S. N., under whose supervision the experiment was made.

The briquettes used were obtained by the U. S. S. *Ranger* from a French steamer at Guayaquil, Ecuador. They were made in Havre, France, of Welsh coal slack. Their age was not known. The dimensions of each briquette were 11½ inches by 8⅜ inches by 4½ inches; approximate weight, 17.6 pounds; specific gravity about 1.27. The word "Havre" and an anchor were stamped on one face of each briquette.

It requires about double the time to properly stow bunkers with these briquettes that it does with coal that will run.

The briquettes, at the rate of combustion used in the experiment, burned freely with little flame and almost no smoke; burning to a fine white ash mixed with a moderate percentage of slaggy clinker that formed a partial coating over but did not cling to the grate bars.

Before making the experiment, the sea suction valves to the feed pump were tested and found to be tight. All discharge connections of the feed pump, leading to other than the feed valve of the boiler, were blanked off.

The feed water was taken from the river Guayas. A small barrel, filled from the ash hose, was placed on a platform scale,

and each barrel of water used was weighed and then emptied into a larger barrel, from which it was taken by a suction pipe of the feed pump.

The coal was weighed as it came from the bunkers.

The ashes were weighed while in a dry state.

At the beginning of the experiment the heights of the water in the boiler and in the larger barrel were noted, and also the condition of the fires. At the end of the experiment the water in the boiler and in the barrel was brought to the same levels as at the beginning, and the condition of the fires was made as nearly the same as could be judged.

During the experiment, which was carried on while distilling, the steam pressure, pounds of coal consumed per hour, and height of water in boiler were evenly maintained.

The boiler was a cylindrical one with two plain internal furnaces joined to a common combustion chamber, the tubes returning above the furnaces. Material of boiler and tubes, steel. Built in 1892 at the Navy Yard, Mare Island, California. It was tight and clean. The following are the important dimensions:

Diameter of boiler, feet	9
Length of boiler, feet and inches	8–5
Number of furnaces	2
Diameter of furnaces, inside, feet and inches	2–10
External diameter of tubes, inches	2½
Length of tubes, feet	6
Length of grate, feet and inches	5–4
Width of grate, feet and inches	2–10
Grate surface in boiler, square feet	30
Area through tubes, square feet	4.6
Area through smoke pipe, square feet	19.63
Total heating surface in boiler, square feet	736.26
Ratio of grate to heating surface	1 to 24.54
Ratio of grate surface to area through the tubes	6.5 to 1
Height of chimney above grates, feet	45

Results of experiment:

Duration of experiment, 24 hours. (From 1·15 P. M., July 25, 1895, to 1·15 P. M., July 26, 1895.)

COAL.

Total pounds consumed	2,788
of refuse	461
of combustible	2,327
Per cent. of refuse	16.5
Pounds of coal burned per hour	116.1
combustible burned per hour	97
Pounds of coal per square foot of grate, per hour	3.87
combustible per square foot of grate, per hour	3.23

FEED WATER.

Total number of pounds pumped into boiler	19,437.75
Mean temperature of feed water, degrees Fahr.	80
Steam pressure, per gauge, mean, pounds	22
Mean number of pounds of water vaporized per pound of coal from the temperature of feed water at the temperature of boiler steam	6.97
Mean number of pounds of water vaporized per pound of combustible	8.35
Mean number of pounds of water vaporized per pound of coal from and at 212 degrees	7.96
Mean number of pounds of water vaporized per pound of combustible	9.54

SHIPS.

UNITED STATES.

Battleships Nos. 5 and *6*.—The general features and dimensions of these two battleships, authorized by the last Congress, are as follows:

Length between perpendiculars, feet	355
on load water line, feet	368
Beam, extreme, feet and inches	72–2½
Draught, mean, feet (normal)	23–6
Displacement at this draught, tons	11,500
Speed, knots	16

There will be two balanced double turrets, oval in shape, at each end, the lower part of each turret containing two 13-inch guns, and the upper part two 8-inch guns. The four guns, with their turret, will be revolved together. There will be fourteen 5-inch rapid fire guns on the main deck, protected by casemate of 6-inch armor, and twenty 6-pounder rapid fire guns mounted above and below the main deck, besides ten machine guns.

The engines will be twin screw, triple expansion, and of 10,000 I.H.P. when the engines are working at 120 revolutions per minute, with a steam pressure of 180 pounds per square inch. The general arrangement of machinery will be similar to that of the U. S. S. *Iowa*.

Gunboats 10, 11, 12 and *13*.—Four of the composite vessels authorized by the last Congress. They will be single screw vessels, barkentine rig, spreading 11,000 square feet of canvas, and have been designed specially for distant cruising. Their particulars are:

Length on water line, feet	168
Breadth on water line, feet	36
Draught, normal, forward and aft, feet	12
Displacement on above draught, tons	1 000

Coal carried on above draught, tons	100
Bunker capacity, tons	238
Indicated horse power	800
Speed, knots	12

The framing will be of steel from the keel up to and above the water line; the upper edge of the wood plank will lap the top side plating about three feet. Plank of Georgia pine will be worked on the frames, secured thereto by composition bolts in such manner as to prevent galvanic action. The outside surface of the plank will be coppered.

No plating will be worked on the under water body of the vessel, except the keel plates, a strip of plating on each side of the keel plates under the boilers to form the lower portion of a water tank and narrow strips for the plates under the longitudinals and bilge keels. The entire top sides will be plated as on steel vessels.

Throughout the machinery space, an inner bottom of plating will be worked, giving added strength to this part of the vessel.

The controlling idea in the design of the machinery has been to secure economy under cruising conditions, and efficiency for long periods; and less attention has, therefore, been paid to reduction of weight than to the attainment of these objects.

The engines are of the vertical triple-expansion type, with cylinders 15¼, 23½ and 36 inches in diameter, and a stroke of 20 inches, and have been designed to run at 150 revolutions per minute at full power. The condenser is cylindrical, and contains 1,120 square feet of cooling surface. The air and bilge pumps are worked from the L.P. crosshead, and there is also a connection for running the flushing pump from the engines; the circulating pump is of the centrifugal type. A disconnecting coupling is provided, so that the screw may revolve freely when under sail alone.

The boilers are two in number, of the cylindrical, return tubular type, and are placed in a compartment forward of the engine with a bunker between the engine and fire rooms. They are 10.5 feet diameter and 10.5 feet long, each with two corrugated furnaces 36 inches in diameter, and have a combined grate

and heating surface of 78 and 2,500 square feet respectively. The tubes are 2¾ inches diameter. Moderate forced draft will be used, the air to be supplied by two blowers delivering through the back of the boiler into closed ash pits.

The battery will consist of six 4-inch, four 6-pounders, and two 1-pounders, and will be disposed in this order: Four 4-inch on the gun deck amidships, two on either side, and two 4-inch on the main deck, one forward and the other aft; two 6-pounders forward on the gun deck, one on either bow, and the other two amidships between the 4-inch guns; the 1-pounders on the main deck.

Gunboats 14 and *15*.—These are two remaining gunboats authorized at the same time as the preceding ones, and differ from them chiefly in having twin screw engines and steadying sail only. The system of construction and the battery are the same as in the single screw boats. Their particulars are:

Length on water line, feet	174
Beam at water line, feet	34
Draught, mean normal, feet	12
Displacement at above draught, tons	1,000
Coal carried on above draught, tons	120
Bunker capacity, tons	250
Indicated horse power	800
Speed, knots	12

From the dimensions above given, it will be seen that the twin screw boats have not as fine lines as the single screw ones.

The engines will be vertical, of the triple-expansion type, and will be placed in a common water tight compartment. The cylinders are 12, 18¼ and 28 inches diameter, and have a stroke of 18 inches. The revolutions at full power are intended to be 200. There is one condenser common to the two engines, and of the same size as that in the single screw boats, and the arrangement of pumps and boilers is the same. The grate surface is 78, and the heating surface 2,500 square feet.

Torpedo Boats Nos. 6, 7 and *8*.—These boats are similar in general design and construction to *Torpedo Boats Nos. 3, 4* and *5*, described on page 152 of the current volume of the JOURNAL,

but are larger, and have been designed for greater speed. Their particulars are:

Length on water line, feet	170
Breadth at water line, feet	17
Draught, mean, feet	5.5
Displacement, tons	180
Indicated horse power	3,200
Speed, knots	26

The engines are arranged as in the previous design of torpedo boats, each in a separate water tight compartment. They are of the inverted-cylinder, direct-acting, triple-expansion type, with cylinders 14½, 23 and two of 26 inches diameter, and a stroke of 18 inches, and have been designed to run at about 400 revolutions per minute at full power. The valves are of the piston type, one for the high and two for the intermediate and low pressure cylinders, and are worked from a counter shaft geared to the crank shaft. The propellers will be about 6 feet diameter and about 7.5 feet pitch.

Steam at 250 pounds pressure will be furnished by three water tube boilers, two of which will be placed in a compartment forward of the forward engine, with a common fire room between them, and the other in compartment abaft the after engine room.

The total weight of machinery with water, spare parts, etc., is not to exceed 92 tons.

The appropriation for the construction of each of these boats, including armament, is limited to $175,000.

The trial will be of two hours' duration, during which the speed must average 26 knots, with a penalty at the rate of $10,000 a knot down to 25 knots.

ENGLAND.

Terrible.—The first class sheathed cruiser, a few of the particulars of which were given on page 197 of the last volume of the JOURNAL, was launched from the works of Messrs. James and George Thomson, Clydebank, on the 27th of May. The following details are from the "London Times" and "Engineering":

Length over all, feet	538
between perpendiculars, feet	500
Breadth, extreme, feet	71
Depth to upper deck, feet	43.25
Draught, mean, feet	27
Displacement, tons	14,200
Coal capacity, tons	3,000
I.H.P., natural draft	25,000
Speed, knots	22

The hull is built on the double bottom principle, the outer and inner skin being carried up to the level of the protective deck, which is also supported on bulb beams and on the water tight bulkheads. The two bottoms are 4 feet apart at center and 2 feet 6 inches at the bilge, increasing to 4 feet at the protective deck level. In the region of the machinery the depth is increased to 8 feet and the section strengthened. A series of plate girders bind the bottoms together with thwartship intercostals. There is no center line keel, the external keel being the central strake, consisting of two thicknesses of plates. The stem, weighing 15 tons, and the sternpost and A frames, of 50 tons, are of phosphor bronze. To the details of construction we may refer in a subsequent article.

The shell plating is of mild steel. The ends of the plates are secured by double riveted butt straps, and the edges of the plates by double riveted lap joints, the rivets being of steel, and generally $\frac{7}{8}$ inch in diameter. As is now usual in war vessels intended to keep the sea without docking for a great length of time, the steel plating of the hull is sheathed on the outside with 4-inch teak planks which are securely fastened to the steel plates by gun metal screw bolts, the heads of which are let in below the surface of the teak plank to the extent of 1 inch, and this is filled in with Portland cement, to preclude any metallic action between the copper sheathing and the steel shell. The width of the teak planking is about 12 inches, and the spacing of the bolts about 2 feet 6 inches. The seams are caulked thoroughly water tight, and "payed" with pitch, the wood sheathing being finally covered with tarred paper before the copper is nailed upon it. Bilge keels have been fitted, in accordance with the experience with

recent battleships. These keels have a depth of about 3 feet and extend for a length of 224 feet. They are formed of solid logs of teak, V-shaped in section, secured to the shell plating of the vessel by 1-inch gun metal screw bolts screwed through the plating of the outer bottom, and fastened with nuts. The surface of the bilge keels is covered with rolled brass plates, which, at the base of the keel, abut against the copper sheathing, and form a continuation of it. These brass plates are secured by ½-inch wood screws.

The ship has been built specially strong along the machinery space. The bar keel plating forming the central strake is 1⅜ inches thick, and the longitudinal girders are here 8 feet deep, although they are only 4 feet deep in other parts of the ship, while the web plates are increased from 20 pounds to 25 pounds per square foot. The sole plate of the engines is bolted to plates 1¼ inches in thickness. These are worked horizontally upon the upper edges of the longitudinal girders. The protective deck beams are 9 inches deep, of angle bulb section, and the 4-inch protective deck is in three thicknesses. The upper frames of Z-bar section, are 14 pounds weight per foot, with plate frames at 10 feet intervals.

The stem, sternpost, rudder, and the brackets for carrying the screw shafts are all made of phosphor bronze, the twin screw propellers being of manganese bronze. The total weight of bronze used is 120 tons, excluding the weight of the twin propellers, which are each 21 tons. The stem weighs 15 tons. It is of the usual ram form now universally adopted by the Admiralty. The ram projects 15 feet beyond the perpendicular line of the bow. The rudder is partly balanced, and has an area of 250 square feet. The rudder frame is also of bronze, and weighs 21 tons. The open spaces between the arms of the frames are filled in with pine, and on each side the rudder is plated over with rolled brass plates.

There is no side armor, but the protective deck has a greater rise of arch than in any cruiser yet built. The crown of the armored arched deck is 3½ feet above the water line at the center of the vessel, while at the sides the edges of the deck join the

hull 7 feet below the water level, whereas it is usually only 5½ feet. The rise of the arch is thus 10½ feet, and the deck is 4 inches thick, except towards the fore and after end, where it is 3 inches. It is formed of three layers of mild steel plates riveted together. In this case, moreover, the machinery, although of a vertical type, is wholly under the protective deck, the length of stroke and of the connecting rods of the propelling engines having been reduced, so that the cylinders would not, as in most previous cruisers, project above the deck, and thus necessitate armored protection round the cylinders. Further protection is afforded by coal bunkers extending for the length of the machinery above and below the protective deck, a distance of 252 feet of the central portion of the vessel, or about one-half of the total length. These bunkers form, when filled with coal, a solid belt. The coal thus carried totals 3,000 tons, giving the cruiser a good radius of action. The bunkers are subdivided by water tight transverse bulkheads, so as to limit the loss in buoyancy caused by a shot entering the side of the vessel. Again, the hull is divided into 236 water tight compartments. Some, of course, are of small size, while others, such as those containing the boilers and engines, are of considerable capacity. The space given up to machinery—252 feet long—is divided by a middle line longitudinal bulkhead and several transverse bulkheads into ten compartments, of which two are utilized for the twin set of triple-expansion four-crank engines, and eight for the 48 Belleville boilers. The bulkheads and longitudinal division walls for the coal bunkers are utilized as much as possible for the supporting of the protective deck, in addition to the beams already referred to.

The armament consists of two 9.2-inch, 22-ton guns, twelve 6-inch rapid fire, sixteen 12-pounders, nine machine guns, and four torpedo tubes. One of the 9.2-inch guns is mounted on the forecastle and one on the poop, 32½ and 37 feet respectively above the load water line. They are mounted in barbettes, and are protected by dome shaped armored shields revolving with the gun. Of the 6-inch guns, eight are on the main and four on the upper deck, two on each deck firing ahead and two astern. Two of the 12-pounders also fire ahead and two astern. The 6-inch guns

will be most effectively protected by Harveyized steel armored casemates, 6 inches thick, completely surrounding the gun, while the shot and powder are conveyed along passages immediately under the protective deck, and surrounded by the coal bunkers, which form a belt of great depth along the machinery spaces. From this passage to the inside of the casemates the ammunition is raised in an armored tube, so that in no case is it for any time exposed to the enemy's fire.

The conning tower, which is located on the forecastle deck, is circular in plan, having an internal diameter of 9 feet 6 inches, and is formed of 12-inch steel faced armor. The aperture for entry to the tower is protected by a heavy steel shield. All the pipes, wires, etc., passing from the conning tower to below the protective deck, are in a strong armored tube 9 inches in internal diameter and of steel 9 inches thick.

The protective deck is chiefly utilized for the stowage of coal, and also provisions, stores and water. On the main deck, which is the next above the protective deck, and the first above the water line, are mounted eight 6-inch quick firing guns, while the remaining four 6-inch guns are on the upper deck, and the two 9.2-inch 22-ton breach loading guns in barbette on the level above, on the forecastle and poop. The whole of the remainder of the main deck is devoted to the cabins for the officers and the messing and sleeping quarters for the crew, the total complement of officers and men being about 900 all told. Above the main deck is the upper and chief structural deck of the ship, on which are situated commodious quarters for the admiral and captain and their numerous staff at the after end of the vessel below the poop, while at the forward end under the forcastle there is additional accommodation for seamen. The topmost deck, as already stated, is called the boat deck, and has a width of only 16 feet along each side of the ship.

There is a bridge over the top of the conning tower. On the bridge is a chart house, with binnacle, another steering wheel, and the engine telegraphs, &c. At each side of the bridge is also a powerful searchlight. On the top of the chart house again

is a flying bridge, this latter navigation platform being 52 feet above the load water line.

Immediately aft of the bridge is the foremast, which carries two fighting tops. In each there will be mounted two quick firing guns, while above this again there is a platform on which a search light is to be mounted. The mainmast carries one military top and a search light platform above. The masts are 36 inches in diameter, and are tubular, with hoists for the ammunition supplies. Each mast is to carry a derrick for lifting in and out the boats. The derrick on the main mast is specially strong, of steel, 18 inches in diameter, for lifting in and out small torpedo boats. Two powerful crab steam winches are fitted on the upper deck for working the after derrick. The largest boat carried has a length of 56 feet. Each mast has two yards, which are not for setting sails, but for hoisting signals. Between the two masts wire rope jack stays are stretched for hoisting additional signals, and there is a second stay on which a traveler can be mounted for lifting the covers of the four funnels, ventilators and heavy weights on the deck.

The steering gear is of the screw type, and is placed immediately under the protective deck and aft over the rudder, which is of the balanced type, and has an area of 250 square feet. The gear consists of a double-threaded right and left-handed screw on an 8-inch shaft, which carries a nut on the right-handed and another on the left-handed portion of the screw. The revolution of the shaft causes the nuts to approach or recede from one another. The motion of the nuts is transmitted to the cast steel crosshead on the rudder stock by means of heavy steel rods 10 inches in diameter and 10 feet long. The rudder stock is cast in one piece with the rudder frame, and is of manganese bronze 24 inches in diameter, but with a 9-inch hole cored in it to reduce the weight. A brass stuffing box has been placed at the point where the rudder stock passes through the sternpost, to maintain water tightness. The weight of the rudder is taken up on a series of eight gun metal rollers 6 inches in diameter, working on a roller path bolted to the sternpost. The steering gear is actuated by two powerful steering engines, each having two vertical cyl-

inders 13 inches in diameter by 10-inch stroke. The engines are in duplicate, to avoid the chance of a breakdown. They are placed in the engine room, and the power is transmitted to the gear by hollow shafting 6 inches in diameter carrying the spur gear. The vessel can also be steered by four handwheels 6 feet 6 inches in diameter placed on the same shaft as the nuts, the gear being connected or disconnected to the steam engine or handwheels at will by a powerful screw clutch.

The whole of the wheel gearing throughout the entire system has been machine cut, so as to reduce backlash and noise to a minimum. The motion of each of the steam steering wheels corresponds to that of the ordinary hand steering wheels, and they are carried on gun metal pedestals, having indices to show the position in degrees of the rudder to starboard or port. In addition to the brass dials, those on the upper deck are fitted with glass segments and lanterns for illuminating the inside at night, and have the necessary figures and the information burned into these glass segments.

The engines are of the four-cylinder triple-expansion type, developing a total power of 25,000 indicated horse power under natural draft conditions. Each set of engines is separated by a longitudinal water tight bulkhead, which extends the whole length of the machinery space. The diameters of cylinders are: high pressure, 45 inches; intermediate, 70 inches, and the two low pressure cylinders, 76 inches, the length of stroke being 4 feet. The high pressure cylinders are placed at the forward end, and are fitted with piston valves of the inside type, having improved adjustable packing rings, while the other cylinders are fitted with treble ported flat valves, having a special type of relief frame to relieve them of steam pressure, and the weight of all the valves is suitably balanced in order to reduce the strain on the valve gear as far as possible.

The cylinders, which are entirely independent castings, are bolted together to provide sufficient longitudinal stiffness; and, to further increase their stability in case of ramming, &c., strong struts are fitted between the high pressure cylinder and the forward structure of the vessel, as well as transversely between the

respective cylinders in each engine room. Each cylinder is supported on four cast steel columns. The barrels of all the cylinders are made of special close grained cast iron, and are steam jacketed. The valve gear is of the double eccentric link motion type, and is reversed by means of a double cylinder engine attached to one of the cast steel front columns at the level of the starting platform and beside the starting handles. Each of the reversing levers is provided with screw gear, so that the valves of each cylinder may be linked up independently.

The pistons, cylinder covers and steam chest doors are of cast steel. The pistons and connecting rods are of Siemens Martin steel, and metallic packing has been employed for all the stuffing box glands of the piston rods and valve spindles of the main engines, as well as for all of the auxiliary engines throughout the vessel. The crankshafts are hollow, and each consists of four interchangeable pieces, 20 inches in external diameter at the journals, and 10 inches in internal diameter. The crank arms are cut away as much as possible for lightness and for convenience in fitting the centrifugal lubricators. The thrusts are of the horseshoe type, each with eight collars. The thrust shafts and propeller shafting are also hollow, the shafting being $18\frac{1}{2}$ inches in diameter inboard and 20 inches in diameter outside the ship. As the vessel is copper sheathed, the portions of the shafting aft of the stern tube stuffing box have been cased with gun metal, as described in a previous article. The propellers are three bladed, 19 feet 6 inches in diameter, and work inwards, recent experiments made by the Admiralty warranting this departure. The bosses are of gun metal, and the blades of manganese bronze, secured to the bosses by large forged naval bronze pins.

The tube casings as well as the ends of the condensers are built up entirely of naval brass plates riveted together. The minimum weight possible is thereby secured, and this condition is of the greatest importance, as a combined cooling surface of 25,000 square feet is required in the *Terrible*. The steam is condensed outside the tubes, which are $\frac{5}{8}$ inch in external diameter by .05 inch thick, the circulating water passing through them.

The water is supplied by four large 24-inch Gwynne's centrifugal pumps, each being driven by an independent engine. The pumps, with steam of 150 pounds pressure, are capable of discharging 1,500 tons of water per hour from the bilge.

In addition to the two main condensers, there are two for auxiliary purposes having a combined cooling surface of 3,000 square feet. The circulating water is supplied by two 9-inch centrifugal pumps.

Besides the auxiliary engines already noticed, a double cylinder reversible engine is conveniently placed above the starting platform, on one of the aft columns which support each of the aft low pressure cylinders, for the purpose of turning the engines. This is effected by a set of compound worm gearing, the worm-wheels having machine cut gun metal teeth, the main worms being of manganese bronze. These engines are capable of turning the main engines completely round in eight minutes with a steam pressure of 150 pounds, and a hand gear has also been arranged for the same purpose.

There are two air pumps for each main engine, one worked from the high and the other from the forward low pressure cylinder.

The propeller shafts are carried in brackets or A-frames of the form usually adopted by the Admiralty. In the case of the *Terrible* the shaft projects through the side of the ship, overhanging to the extent of 50 feet. The A-frame is pear shaped on plan, the thinnest edge being placed aft, in order to avoid eddy making. The longest axis of the section is 3 feet 9 inches, and the shortest 12 inches. The ends of the A-frame, after passing through the side of the ship to the interior, are flattened out into broad palms, which are secured to strong plate steel girders by steel rivets. The water tightness of the arms where they pass through the shell is maintained by angle iron collars, both inside and outside the shell plating. The A-frames weigh about 50 tons. To guard the shaft against hawsers, etc., there is around it a casing or tube of rolled brass plates, stiffened by longitudinal angle bars.

The platform and orlop decks, being below the protective deck, are utilized for the stowage of ammunition and torpedoes, and

also for the steering gear, capstan engine, ventilating and air compressing engines, and for some of the dynamos. Being essential to the fighting efficiency of the ship, these are necessarily put below the protective deck. At each end of the vessel on the orlop deck is a torpedo compartment, each containing two tubes for the discharge of 18-inch Whitehead torpedoes. The fact of the tubes being below the protective deck, and the weapons being discharged below the water level, overcomes the possibility of explosion by the enemy's shell before being ejected. The ammunition magazines are also below the protective deck, and an interesting departure has been introduced in providing an ammunition passage on either side of the ship immediately below the protective deck and right through the lower coal bunkers, that is to say, there are coal bunkers on either side and below the passage, with the protective deck immediately above, and over that again more coal bunkers. The powder and shell for the 6-inch guns on the main and the upper decks will be taken from the magazines and conveyed on trolleys along this ammunition passage until below the gun, where the powder and shot will be hoisted through a protected tube into the armored casemate in which the gun is mounted. Thus the powder and shell are never without protection from the enemy's fire. There is also an ammunition passage on the protective deck on either side of the ship for serving the 12-pounder and smaller guns.

There are in all 48 boilers for the *Terrible*, of seven and of eight elements, located in eight boiler rooms, and arranged symmetrically on each side of the central longitudinal water tight bulkhead. The four after spaces on each side of the vessel contain eight boilers, respectively arranged in three groups, the forward and after groups each consisting of two boilers placed side by side, and the center group of two pairs of boilers placed back to back and fired from awthartship stokeholds.

The remaining 16 boilers are placed in four forward boiler rooms, situated likewise in pairs on each side of the central bulkhead, and fired from longitudinal stokeholds. This difference in arrangement is necessitated by the fineness of form of the vessel at this part. The funnels are four in number, of oval section, one

to each transverse division. They are of different cross dimensions, to suit the number of boilers leading to each, but the longitudinal dimensions have been kept the same in all four, in order to accord with the general symmetry of the ship. The height of each funnel from grate is 80 feet. To supply the air required for suitable deflection of the furnace flames and for admixture with the gases for insuring complete combustion, eight air compressing engines are supplied and fitted in the boiler rooms, there being one double cylinder compressor for each of the four large compartments, and a single cylinder compressor for each of the four smaller forward spaces. The air is injected into the furnace from a nozzle box placed on the front of the boiler immediately above the furnace doors, and extending the whole width of the fire grate. This air is discharged over the fire through small nozzles, which divide it into thin streams. The total grate surface is 2,200 square feet, and the total heating surface 67,800 square feet, which should give an ample margin of boiler power even when compared with merchant service proportions. The working pressure in the boilers is 260 pounds and is reduced to 210 pounds in the high pressure steam chest.

In the case of the *Terrible's* boilers, the junction boxes are malleable cast iron, $\frac{5}{16}$ inch thick, and the tubes, mild steel lap-welded, 6 feet 8 inches in length, $4\frac{1}{2}$ inches outside diameter, and varying in thickness from $\frac{8}{8}$-inch for those of the lower, to $\frac{3}{16}$-inch for the uppermost rows. The tubes are screwed into the back boxes, the pitch of the screw on the tube being very slightly different from that of the box, so as to form a metallic joint between them. A jam nut is added for greater security. A similar device is employed for the front ends, with this exception, that, instead of both tubes entering the box, one is connected by means of a screwed coupling nut to a projecting nipple. This arrangement is adopted to facilitate the removal of the tubes which form the elements. The casings which inclose these elements are particularly deserving of notice, from the careful manner in which they have been designed so as to secure the requisite stability, together with a minimum of weight. The radiating surfaces of these casings, as well as of the steam collectors, have been covered

with a layer of asbestos 3 inches thick, which is in turn protected by thin plates securely and neatly fastened. The length of pipe in each element is 120 feet.

The main steam pipes are of mild steel, as are also the receiver pipes. On each side of the central longitudinal bulkhead through the machinery space, there are three lines of piping from the boilers to the engines, making four in all.

There are three feed pumps in each engine room and six in the stokeholds, making twelve feed pumps in all.

To effect the efficient ventilation of those portions of the ship underlying the protective deck and of the engine and boiler rooms, 18 steam fans of large diameter are employed. Two fans, 6 feet in diameter, are placed forward of the machinery space, and by means of two large trunks, air is led to the submerged torpedo room air compressing space, and to the capstan engine room, all these compartments being on the orlop deck. Where these trunks have occasion to pass through water tight bulkheads, vertical and horizontal automatic valves are fitted over the opening, so that, in the event of a compartment being flooded, the adjacent compartments are kept intact.

Two fans of the same dimensions as those forward are also placed on the orlop deck abaft of the machinery space, with air trunks extending through the auxiliary machinery space, ammunition passages, 12-pounder and 6-inch shell rooms, submerged torpedo room, and steering compartment, in which latter space the trunk stops. Branches are carried down to the platform deck aft as well as forward, and after supplying the engineers' store rooms, branch trunks are led to the 6-inch magazines, 3-pounder and small arms magazine, torpedo head magazine, gunners' store rooms, and finally to the 9.2-inch shell rooms. The hold is supplied in a similar manner to that already described for the forward compartments. Branches with louvres are led along shaft passages, port and starboard, supplying the 12-pounder and the 9.2-inch magazines. Provision is also made for thoroughly ventilating the double bottom.

An equally efficient service of exhaust trunks is fitted throughout the ship, by which means the foul air is carried aloft. In

each of the engine rooms a steam fan 7 feet in diameter has been placed for the purpose of extracting the heated and vitiated air. In connection with the inlet apertures of these fans a system of air trunks has been led to those parts of the engine room where heated air is likely to lodge, so as to draw it off and expel it overboard. In connection therewith, screens, suitably placed in the engine room hatch, are employed to direct the down coming fresh air to the more important positions from which the engines are started or manœuvred. The remainder of the fans are placed in the boiler rooms, two in each of the four after, and one in each of the four forward compartments. These are 6 feet 6 inches in diameter and are double breasted, with a diaphragm plate in the middle, and may be regulated from either the fan platforms or the stokehold floors. The discharge apertures and trunks of these fans have been arranged to insure a uniform supply of air throughout, and in the event of the boiler rooms being closed these can maintain an ample supply of air to all the furnaces.

The air compressing machinery for charging the torpedoes consists of four complete sets of air compressing engines and pumps, and eight sets of air reservoir tubes with separators and charging columns. Two engines are placed in the forward part of the vessel, and the other two in the after end. Each has three air pumps of large size, and all the parts of these engines, as well as of all the other auxiliary engines throughout, are designed to work at the full boiler pressure of 260 pounds per square inch, which will be the pressure ordinarily employed. The air pressure employed is 1,700 pounds per square inch, the tubes for the separators, charging columns, and air reservoirs being made of the best open hearth steel, great care being taken to secure them of a perfectly cylindrical form and of a uniform thickness throughout. Some indications may be given of the excellence of the workmanship employed in the manufacture of this class of machinery, so as to secure perfect tightness of the joints at each of these tube ends, 50 of which form but one air reservoir, and also of the joints of the intermediate pipes connecting them to the air pumps, as well as of the various valves and fittings of the pumps themselves. The whole of the installation was tested

to the working pressure of 1,700 pounds per square inch, and allowed to stand under this pressure for 24 hours, when it was ascertained that the loss of pressure was under 6 per cent. To attain this result only the very best materials can be employed, and the greatest care has to be exercised in selecting the copper, as well as in obtaining the most suitable alloys of this metal.

The electric machinery for generating the current for internal lighting, search lights, motors, etc., consists of three large sets of condensing engines and dynamos. The engines are of the open fronted compound type, mounted on the same bedplate, and coupled direct to dynamos which are of the direct current type, self regulating, and each capable of maintaining on continuous running 600 amperes, with an electromotive force of 80 volts, at 300 revolutions per minute. Two of these sets are placed in a compartment adjacent to the main engine room and under the protective deck, the third set being placed on the main deck amidships. The electric light installation consists of about 800 50-candle power and 16-candle power lamps, laid out on the double wired, water tight distributing system. In addition to the lighting up of the interior spaces, including coal bunkers and magazines, the decks will be illuminated by powerful lights suspended from the rigging. The compasses, telegraphs, masthead, side lamps, signal lanterns, semaphores, and military tops are all separately lighted and under the immediate control of the officer on deck. Six search lights of about 50,000-candle power each, are fitted up—two on the forward bridge, two on the after bridge, and one on the top of each mast. Each of these powerful lamps can project a beam of light right round the horizon. Electric motors are to be used throughout in lieu of the usual hydraulic appliance—and this applies not only to the training and elevating of the large guns, but also for the ammunition hoists, etc. Submerged torpedoes will also be fired by electricity from the torpedo director house and conning towers.

The remaining pieces of auxiliary machinery may now be briefly noticed. Amongst the more important are the boat-hoisting winches, which are two in number. The barrels are each arranged to take about 240 feet of wire rope, capable of

lifting 17 tons; and the coal hoisting engines, two in number, which are situated on the upper deck. Twelve double cylinder ash hoisting engines, with brake apparatus and automatic stop-gear, are also fitted for removing ashes from each of the stoking platforms and for discharging them overboard. The engineers' workshop is fitted with a double cylinder engine and a complete complement of machine tools, comprising two large and one small lathe, punching and shearing machine, shaping machine, drilling machine, and grindstone, together with a number of benches fitted with vises, the whole making a very complete repairing department. The vessel is also fitted with mechanical telegraphs, and reply gongs between the engine room and the steering positions and to the stokeholds, revolution indicators and counters. Tell-tales, for indicating the direction of rotation and number of revolutions which each of the main engines is making, and a complete system of voice pipes between the engine room and the important stations throughout the vessel are also to be fitted, together with a system of electric bells, pushes and indicators.

The following is a list of the separate engines in the ship:

	Sets.
Main engines	2
Reversing engines	2
Turning engines	2
Main circulating pumps	4
Auxiliary circulating pumps and air pumps	2
Main feed pumps	6
Auxiliary feed pumps	8
Fire and bilge pumps	4
Drain tank pump	1
Distiller pumps	2
Air compressors for air jets in Belleville boilers	8
Fan compressors for stokeholds	12
" engine rooms	2
" ship ventilation	4
Electric light engines	3
Air compressors	4
Steering engines	2
Boat hoisting engines	2
Coal " "	2
Ash " "	12

	Sets.
Engine for workshop	1
Capstans, fore and aft	2
Total engines on board	87

Powerful.—A sister ship to the *Terrible* was launched from the works of the Naval Construction and Armaments Company, Barrow, on the 24th of July. Her construction does not differ from that of the *Terrible*, but there are some differences in the engines, the cylinders of which are 45, 70 and 76 inches in diameter and 48 inches stroke, their total length being 45 feet. The engine columns and bedplates are steel castings of box section, instead of H-section, as in the *Terrible*.

The cylinders are all separate in themselves, but are attached to each other at their tops by cast steel connecting pieces. They have thin cast iron liners, which will be adjusted when hot. The pistons are of cast steel, with deep cast iron junk rings, and the cylinder covers are of steel. The high pressure steam chest cover is of steel, and the other covers are of cast iron. There is a piston valve on the high pressure cylinder, and ordinary flat valves, which have the usual relief at the back, for all the other cylinders. The link motion is of the ordinary description, with steam and hand reversing gear, the steam engine for this purpose being placed on one of the intermediate engine columns. Each valve is capable of being linked up independently by means of a screw and block.

The four-throw crankshaft is in four separate pieces, each of which is interchangeable with any other, and this applies to the cranks in both sets of engines. The main and crankpin brasses are of ordinary Admiralty mixture, lined with white metal. The top end brasses, or crosshead bearings, are of a special mixture of hard metal; the crossheads are Swedish iron; the piston and connecting rods and main bearing caps are of forged steel. As is now usual, the large steam pipes are of steel. They have welded seams, over which there is riveted a butt strap. The turning engine is on the end low pressure standard. The worm-wheels of this are of bronze, and the worms of forged steel. There are two air pumps, one worked from the high pressure

and one from the forward low pressure engine by means of side levers. The thrust bearing consists of one large steel casting, with horseshoe collars and water service as usual. The propellers are three bladed, about 19 feet in diameter. They are of Admiralty gun metal, with blades bolted to the boss.

The *Powerful* was more complete at the time of her launch than are many vessels of this class when placed in the water. All the armor was in place, and also the gun pedestals and a great deal of the cabin fittings, so that the launching weight was brought up to 7,300 tons. In order to take this weight with safety, the ways had been built out a long distance into the channel, and had been made with 5 feet bearing surface on each side, which is a good deal beyond the average width. The cradle had also been very much strengthened forward, dockyard practice having been followed in its general construction. A built up plate of steel, several feet long fore and aft and $\frac{3}{4}$ inch thick, was passed under the ship's keel, being hooked over the poppet heads —the poppets were almost upright—on each side of the cradle. The whole structure was further consolidated by a large number of turns of heavy chain. The interior of the ship was also strutted more than is usual, even for the big and comparatively light scantling ships of this kind. In the neighborhood of the forward part of the cradle this was especially noticeable.

Sultan.—This single screw third class battleship has been given a thorough refit. New decks, cabins and top sides have been fitted; military masts and fighting tops have been substituted for her former sail carrying equipment, a complement of quick firing guns has been added to her original armament, and she has been supplied with modern inverted triple expansion engines, designed and constructed by Messrs. J. and G. Thomson, of Clydebank, Glasgow. Steam is supplied by eight single ended boilers, which are placed in two separate water tight compartments. They are of the marine return tube pattern, 15 feet $2\frac{3}{4}$ inches in mean diameter and 10 feet long, containing four furnaces each. Siemens-Martin steel was used throughout for their construction, and they are designed for a working pressure of 155 pounds per square inch.

Her trials were carried out on the 29th and 31st of May, but the ship was not at her load draught, the mean draught being 23 feet 2½ inches. The results were:

	Natural draft.	*Forced draft.*
Steam pressure	147.7	151
Vacuum	25.5	25.9
Revolutions	88.7	93.8
Air pressure	...	.36
I.H.P	6,531	8,244
Speed by patent log	14.6	15.3

Pelorus.—The contract for the machinery of this new third class cruiser, whose dimensions were given in the last number of the JOURNAL, has been given to Messrs. J. and G. Thomson, Clydebank. The engines are to be of 7,000 I.H.P., under natural draft, and the speed under these conditions 20 knots. Steam is to be furnished by Normand boilers. Her displacement will be 2,135 tons.

Torch.—The trials of this sheathed gunboat, whose dimensions are given on page 203 of the last volume of the JOURNAL, has been completed, with the following results:

	Natural draft.	*Forced draft.*
Duration of trial, hours	8	4
Steam pressure	150.4	153
Revolutions per minute	186 6	203.4
Vacuum	...	27.4
Air pressure, inches of water	...	1.2
I.H.P.	1,163	1,457
Speed by patent log	13	13.4

Sharpshooter.—Trials of the boilers.—On account of the opposition in England to the adoption of the Belleville boiler for the *Powerful* and *Terrible*, and the questions raised as to its reliability, the Admiralty decided to subject the *Sharpshooter* to a series of trials to determine the behavior of her boilers under ordinary conditions at sea. For this purpose, the trials determined on were four in number, the first consisting of four runs of 1,000 miles each, at 1,530 I.H.P.; the second of two similar runs at 1,800 I.H.P.; the third of three runs at 2,000 I.H.P.; and the fourth of

one run of 1,000 miles at 2,150 I.H.P., or until the coal abreast the boilers has been used.

The first and second series were carried out without difficulty with the boilers, but doubt was expressed as to the ability to complete the last trial on account of the excessive vibration of the vessel.

Sturgeon.—This torpedo boat destroyer, whose trials were noted in the last number of the JOURNAL, after having been repaired, succeeded in completing her official trials, her speed on the mile being 27.6, and that for three hours, 27.25 knots.

FRANCE.

Rapid Cruisers Nos. 1 and *2.*—The French Government has recently entered into contract with private establishments for the construction of two triple screw cruisers (*croiseurs corsaires*) to have a speed of 23 knots, and to carry enough coal to steam 7,500 miles at 12 knots. The preliminary scheme contemplated vessels of about 8,500 tons displacement, not more than 425 feet long, and draught aft not to exceed 24.5 feet; but the plans on which awards have been made are for vessels of about the size of the *Columbia* and *Minneapolis.*

The main battery, composed exclusively of rapid fire guns, comprises two 6.5-inch mounted amidships, one forward and the other aft; six 5.5-inch, two of which are on the upper deck with ahead and astern fire, and four in redoubts on the battery deck, two forward and two aft. All are protected by 2.12-inch shields. For the guns which fire ahead, the regulation allowance of ammunition is provided for in the weights; for the others it will be reduced one-third, but the magazines are to be large enough to stow the full amount, and, if possible, one-third more.

The secondary battery consists of ten 47-mm. guns mounted on the superstructure.

The protective deck will be 1.26 inches thick on the flat and 1.75 inches on the slope, and will be 2.6 feet above the water line amidships and 4.6 feet below it at the sides.

The conning tower will have 7.87 inches of Harveyized armor.

She will have no automobile torpedoes and will not be provided with torpedo nets.

The requirements for the machinery are that the engines shall be vertical, of either the triple or quadruple expansion type, and strong in construction; that the boilers shall, if possible, be of the water tube type; and that the speed of 23 knots shall be attained with a mild forced draft in closed fire rooms. The endurance of 7,500 miles, at 12 knots, is to include the coal necessary for running the auxiliaries, distilling water, &c.

In the construction of the hull, special attention is to be given to the strength and shape forward, in order that they may be driven into a sea at high speed. As far as possible, wood work will be prohibited, especially in the upper works.

There will be a double bottom below the machinery space, and trimming tanks forward and aft.

The rig will be two pole masts without yards, but with light platforms for search lights.

Stowage will be provided as follows: For provisions, 90 days; for water, 20 days.

Masséna.—This triple screw battleship, designed by M. de Bussy, was launched from the Chantiers de la Loire, St. Nazaire, on the 24th of July. Her dimensions are:

Length on water line, feet	363.5
Breadth, feet	66.6
Draught, aft, feet	26.8
Displacement, tons	11,760

She is designed to make a speed of 16 knots on 9,300 I.H.P. with natural draft, and 17.5 with assisted draft on 13,500 I.H.P. The engines are triple expansion, and the boilers, 24 in number, of the Lagrafel-d'Allest type.

She has a complete armor belt varying in thickness from 9.8 to 17.7 inches, and the armor of the large turrets is 13.8 inches on the moving and 15.7 on the fixed portion. The protective deck is 3.5 inches.

The battery comprises two 12-inch guns in central turrets, one forward and the other aft, two 10.6-inch in side turrets, eight 5.5-

inch in broadside turrets, and eight 3.9-inch on the superstructure, besides thirty 47 and 37-mm. rapid fire guns and five torpedo tubes. The 5.5-inch guns are protected by 3.9 inches of armor.

Bouvines.—A sister ship to the *Jemmapes*, described on page 805 of the last volume of the JOURNAL, completed her trials in June and July last. The full power trial lasted two hours, the I.H.P. being 8,680, and the speed 16.05 knots. About a week afterwards she had another trial with twelve boilers in use; this lasted twelve hours, and the results are said to have been satisfactory, both as regards I.H.P. and economy, but the temperature of the fire rooms was very high, trouble of the same kind having been experienced on the former trial. Her boilers are of the D'Allest type, as stated in the last number of the JOURNAL.

Her final preliminary trial was made in March, with 115 revolutions of the engines and 8,200 I.H.P.

GERMANY.

Aegir (formerly "*T*").—A fourth class battleship of the *Siegfried* class has recently been added to the German Navy. Her dimensions are:

Length on water line, feet	236.2
Breadth at water line, feet	50.52
Depth, feet	35 56
Draught, mean, feet	17.39
Displacement, tons	3,542

She has an armor belt of nickel steel 8.66 inches thick, backed by 7 to 8 inches of teak, and extending about half her length, the citadel above being 4 inches thick on sides and the bulkheads 8 inches. The gun turrets and ammunition shafts also have 8-inch armor. A cork belt 31 inches thick extends from the ends of the armor belt forward and aft.

The battery consists of three 9.45-inch, ten 3.4-inch, eight machine guns, and four torpedo tubes, two of which are submerged.

The engines are twin screw, triple expansion, with cylinders 26, 40 and 63 inches in diameter, and 29.5 inches stroke, and are designed for 2,400 I.H.P. each with 175 pounds boiler pressure.

The air pumps are independent, and have three steam and two water cylinders for each main engine. The propellers are 11.5 feet diameter and 12 feet pitch. Steam is furnished by eight Thornycroft boilers of the old type, having a combined grate surface of 274 square feet.

Her bunker capacity is 223 tons.

ITALY.

Aquila.—The following account of the accident on board this torpedo boat is given by a Spezia correspondent of the London "Standard."

"Early on the morning of the third of July the *Aquila* received orders to put to sea to undergo full speed steam trials, with the object of ascertaining if she could be utilized as a torpedo chaser. Consequently, the speed and head of steam under which she was going at the time of the catastrophe must have been excessive, for a breakdown occurred in the reversing gear of the forward engines, a portion of what is called Stephenson's link snapping from the violent vibrations of 300 revolutions per minute. The crown of the furnace collapsed, dragging with it the fore part of the boiler, together with the tubes. The explosion blew down the bulkhead leading into the torpedo room, killing the fireman on duty, and suffocating a sailor who was sleeping there. The steam also forced its way into the engine room through an opening in the bulkhead, over the heads of the engineering staff, severely burning all, and blowing one overboard, together with a ventilator, which broke the ribs of the officer second in command, who was on deck. The Chief Engineer, though severely injured, had the presence of mind to have the fires of the after boiler drawn by two firemen, who remained uninjured, to prevent further accidents, there being no one to superintend the working of the other pair of engines. The survivors signalled to the Semaphore, and also sent a small boat to the nearest village on the coast for assistance, and on the news reaching Spezia two tugboats, with doctors and medical appliances, proceeded to the disabled boat, and towed her to Spezia, landing on their way the

most severely injured at the Naval Hospital at Portovenere. Of the survivors, three have since died, and five or six others are not expected to live. The body of the missing engineer blown overboard was picked up by fishermen at Riomaggiore, terribly burnt about face and head. The steam trials of the *Aquila* were being superintended by Signor Oltremanti, Staff Engineer of the Reserve Squadron, now at Spezia, who happened to be looking down the engine room at the time of the accident, and was severely scalded about the face and head. The *Aquila* was built by Schichau, of Elbing, in 1888, and had a speed of twenty-six miles per hour."

PORTUGAL.

Adamastor.—Orlando Brothers, Leghorn, Italy, have recently received a contract from the Portuguese Government for the construction of a cruiser of the following dimensions:

Length on water line, feet	242.7
Breadth, extreme, feet	35.1
Draught, mean, feet	14
Displacement, tons	1,771

Her battery consists of two 5.9-inch guns, one forward and the other aft, four 4-inch, two 47-mm. and four Nordenfelt machine guns, besides three torpedo tubes, one fixed forward, and two pivoted in broadside.

There will be vertical twin screw triple expansion engines of 3,000 I.H.P. natural draft, when making about 115 revolutions, and of 4,000 I.H.P. under forced draft. The speed expected under the two conditions is 16 and 17.3 knots respectively. The boilers will be four in number, of the gunboat type, and will have three furnaces each.

RUSSIA.

Sokol.—A torpedo boat destroyer, similar to the *Havock* of the British Navy, is building by Yarrow & Co. for the Russian Government, under a guarantee to make 29 knots an hour. Her dimensions are:

Length on water line, feet	190
Breadth, feet	
Draught, mean, feet	7
Displacement, tons	240

She will have twin screw triple expansion engines of 4,500 I.H.P., steam for which will be furnished by eight Yarrow water tube boilers.

Her armament will comprise one 75-mm. rapid fire gun forward in the conning tower, two 47-mm. forward for ahead fire, and one 47-mm. aft, besides two torpedo tubes on deck.

New Cruiser.—The Russian Government has recently entered into a contract with the Forges et Chantiers de la Mediterranée at Havre to build a protective cruiser having the following characteristics:

Length on water line, feet	331.40
Breadth extreme, feet	42.65
Depth to upper deck, feet	35.11
Draught, aft, feet	18.76
Displacement, tons	3,767
Bunker capacity, tons	394
I.H.P.	8,400
Speed on measured base at Cherbourg, knots	20

Her battery comprises six 15-cm., ten 47-mm. rapid fire guns, and four torpedo tubes.

The protective deck is 1 inch thick on the flat and 2 inches on the slope, and the conning tower 4 inches thick.

There will be two four-cylinder triple-expansion engines, working with an initial steam pressure of 170 pounds, and designed to make 128 revolutions when running at full power. Steam will be furnished by eighteen Belleville boilers, in three groups, working under a pressure of 242 pounds. The air pressure to be used on trial is not to exceed $\frac{1}{2}$ inch of water.

Samoyede.—The Thames Iron Works, London, has just completed an armed transport for Russia, whose construction entire has been done in three months from the date of signing the contract. Her dimensions are:

Length on water line, feet	170
Breadth, feet	33
Depth, feet	16.6
Draught, mean, feet	12
Displacement, tons	1,050

She has a single screw vertical engine with cylinders 20, 32 and 50 inches diameter and 24 inches stroke, designed for 1,050 horse power on a piston speed of 600 feet per minute, and a boiler pressure of 160 pounds. She has two main and one auxiliary boiler, the former being 12 feet 3 inches diameter and 10 feet long, and containing 105 square feet of grate and 3,000 of heating surface; the auxiliary boiler is 10 feet diameter and 9 feet long, and works at a pressure of 100 pounds. Her speed is intended to be about 12 knots.

Her battery consists of two 47 and two 37-mm. rapid fire guns.

MERCHANT STEAMERS.

St. Louis.—A general description of this steamer of the "American Line" has already been given in Vol. VI, p. 811, of the JOURNAL.

The *St. Louis* sailed on her first voyage from New York for Southampton on Wednesday, June 5, 1895, and made the voyage in 7 days 3 hours and 53 minutes, at an average rate of speed of 18.37 knots. On her return voyage, the voyage was made in 7 days 7 hours and 11 minutes. The best speed made on the first voyage was 19½ knots, the I.H.P. being a little more than 16,000 with 85 revolutions. The engines were at no time pushed.

The second voyage back from Southampton was made in 6 days 18 hours and 47 minutes. It will be seen that so far no "record-breaking" attempt has been made, such as would be fully and fairly representative of her qualities and power.

The following description and data of the machinery were taken from "Engineering:"

"The main engines are of the quadruple expansion type, but with six cylinders working on four cranks, an arrangement patented by Mr. John Thom, who is associated with the technical staff of the American Line as a consulting engineer. There are two high pressure cylinders, and each of these is placed over one of the two low pressure cylinders. The tandem cylinders are at the forward end, the arrangement being high pressure and low pressure working on the first crank, the same working on the second crank, the second intermediate on the third crank, and the first intermediate on the fourth crank. Steam, of course, is passed from the two high pressure cylinders into the one first intermediate, then to the second intermediate, and thence into the two low pressure cylinders. The diameters of the respective cylinders are: Two high pressure 28½ inches, first intermediate, 55 inches; second intermediate, 77 inches; two low pressure,

77 inches. The stroke in each case is 5 feet. The cylinders are each separate castings, and are supported on A-frames at back and front, the condenser and its pumps being separate and placed in the wings of the ship. The supporting frames are cast in two parts, each part having three sides only, with flanges to the outside for bolting together. The inside is thus entirely open, so that the soundness of the casting is apparent. The cylinders are braced longitudinally by cast iron girders of box section, which also extend between the forward and aft cylinder and the ship's bulkhead, so that there is little tendency to work. These bulkheads are specially stiffened by girders 2 feet deep, built of plates and angle bars. Each high pressure cylinder is carried 24 inches above the low pressure cylinder on cast iron frames on either side, and this clearance enables a manhole to be provided on the top of the low pressure cylinder to admit of examination, &c. The main stop valve is in the engine room, on the same level as the high pressure cylinders; and the inlet to the high pressure cylinder valves is controlled by a balanced piston throttle valve on the main pipe. The steam pipes, it may be said, are all of steel, lap welded, with double riveted flanges, and the largest is 20 inches in diameter.

Piston valves of the Thom's balanced type are fitted throughout, and they are operated by the usual double eccentric link motion, the bent rod being for the astern motion. The eccentric straps are of cast steel filled with Parson's white metal. There are two valves for the low pressure cylinders. Frequently the guide brackets for the crosshead for valve spindles in such cases are insufficient, and the little slackness resulting tends to twist either spindle and snap it. In this case the guides have been brought out on either side to within 10 inches of the valve spindles. Cast brass guide blocks are fitted to the quadrant piece, the guides consisting of a cast steel bracket bolted to the low pressure cylinder. Special arrangements have been made for adjusting any wear. The spindle of the high pressure cylinder valve is worked from the low pressure valve crosshead through a bellcrank lever. And here it may be said that the starting and reversing is done by gearing not dissimilar to Brown's, but without any hydraulic

cylinder. There is a steam cylinder 24 inches in diameter by 30-inch stroke, and the cushioning is by the adjustment of the valve, and also by a spiral spring on the guide spindles.

The cylinders are of cast iron; the second intermediate and the two low pressure cylinders only have jackets, and these drain into water traps which discharge into the hot well tank. Outside all the cylinders are coated with asbestos, hair felt, and covered with sheet steel. Cramps' metallic packing is used throughout. It is somewhat similar to the United States packing, with cast iron rings compressed by a spiral spring. The clearance in the cylinders is on the top of the pistons ½ inch, and below ⅝ inch. The piston rods of the high pressure cylinders are 6 inches in diameter, and in the other cylinders 8½ inches. The connecting rod is fully twice the length of stroke, 11 feet 3 inches centers, and is 8½ inches in diameter at top, and 10 inches at bottom. The connecting rod at top is not forged with the usual U end for the crosshead pins. The crosshead connection is built up. The top of the rod is squared to a T piece, with a hole bored through the two heads. On the bottom of the crosshead itself, at either side, there is forged a projection, which is screwed and passed through the holes and bolted. In other words, the crosshead brasses have a steel T piece with pin forged to the bottom which passes through the holes on the top of the connecting rod. Slipper guides for the crosshead are fitted to one side of the framing. There is a steel flange fitted on either side of the column face, and the slipper works inside it. Between the back of the crosshead and the other frame there is a small gangway to admit of inspection, and to economize weight a hole is bored through the crosshead brasses, which also have the usual piece for adjustment. Lubrication is from a separate tank at the top of the engine skylight, whither the oil is pumped from a supply tank, and whence it passes by gravitation in a series of pipes to the different parts of the engines, the supply being controlled at each delivery by a needle pointed valve.

The crankshaft is 21 inches in diameter, the crankpins 22 inches, the bolts being 5 inches at the bottom of the thread. The cranks themselves are 16 inches broad, the length of pin being 31½ inches,

and there is a 6-inch hole through the cranks and pins. The bearings are 26 inches long, and are of cast steel filled with Parson's metal. They are bolted down with 4½-inch bolts, and in the bottom water is circulated. Here it may be stated that the bedplate is of cast iron box section, 3 feet 4 inches deep and 4 feet 7 inches at the center, the center part, instead of being flat, being dished to the extent of 1 foot. The bases of the standards are fitted to the dished part of the bedplate as well as the flat portion, so as to tend to obviate the radial "working" which sets up torsional vibration and strains.

The ship, it may be said, has a center keel line 4 feet 9 inches deep, from which the side framing rises. This framing is of channel section, 7 inches by 3½ inches by ½ inch, spaced 32 inches apart, every third frame being of web construction 30 inches deep, with face plates running longitudinally and 30 inches broad.

The thrust shaft is 21 inches in diameter and solid, the diameter over thrust rings being 33 inches. There are 13 horseshoe collars, each 2½ inch thick, and the surface on the ahead side is 6,616 square inches. The length of the thrust shaft is 14 feet, and it is secured to the bedplate of the engines. The horseshoe rings are adjustable by a horizontal screw with two nuts for each side, which greatly facilitates the removal of any ring. The turning wheel is immediately aft of the thrust shaft. The engine has two cylinders, 8 inches in diameter by 8-inch stroke. The thrust shaft, by the way, is placed in a recess, and over it, with entrance from an upper platform, is the dynamo room.

The propeller or line shaft is 19 inches in diameter, also solid. It is fitted in lengths of 23 feet, with bearings 14 feet apart. These bearings are 2 feet long, and have cast steel bodies, filled with Parson's white metal. There is fitted to the after length of the shaft a portable coupling. It is in halves, and through each half there is a longitudinal feather 5 inches wide and 2¾ inches deep. The ten bolts were put through the coupling when at a high temperature, the subsequent contraction giving greater binding to obviate slip. This arrangement, which is not usual, is to facilitate the drawing of the shaft for repair. The feathers running longitudinally through each half of the coupling would

not have prevented the shaft from backing out when the engine was going astern, and to overcome this possibility, grooves 1 inch deep were turned in the shaft, forming collars, which engage in collars and grooves on the coupling. There is no outboard shaft, the framing and plating of the ship being bossed out in the same way as in most high speed twin screw merchant steamers now. The stern shaft, which is 21 inches in diameter, is covered with a liner 1½ inches, working in lignum-vitæ bearings, constructed in the old style in strips 3½ inches broad and 1 inch deep, the division between the strips allowing water to circulate. The stern gland is light, but is packed with Tupper's machine plaited flax packing. The bosses of the propellers are of steel, with three blades of Parson's bronze, and these, for the present, are set at a pitch of 27½ feet.

The condensers are separate from the main engines. They are 7 feet 2 inches inside diameter, and the tubes, which are of seamless brass, are ¾ inch in diameter and 16 feet 8⅜ inches long. There are six stay rods, and the tubes are supported at two intermediate points between the tube plates. The total condensing surface is 26,170 square feet. The air pumps are also placed in the wings of the ship. There are four for each condenser, and they are of the Worthington type, with steam cylinders 26 inches in diameter and 20 inches stroke. There are 8-inch valves to each of the four buckets. On the voyage across these worked at about 20 double strokes per minute, giving a vacuum of 26½ inches. The air pumps discharge into the hot well tank, which also receives the drainage from all the water traps in connection with the jacket of the cylinders, and with all the auxiliary machinery, and all is subsequently passed into the feed. The centrifugal pumps for the condenser are also of the Worthington type. They are driven by engines with 12-inch cylinders by 14 inches stroke. The discs are 3 feet 6 inches in diameter, with a 6½-inch inlet and 3¾ inches discharge. The water, after it has been used for condensing, instead of being run overboard, is forced up to a tank on the topmost or boat deck, where, at a temperature of 115 degrees, it is stored in a tank available for use in baths or for gal-

ley or pantry use. There is also a cold salt water tank on the same deck.

The feed water is passed through Worthington's feed heater, being raised to 210 degrees, while the same company's vertical feed pumps are in use. The evaporator and distiller are on Quiggan's system, while the installation of general pumps for sanitary duty, for the hot sea water to baths, and for bilge duty, is on the Worthington system; and here it may be stated that all the auxiliary machinery exhausts into a separate condenser.

We come now to the boilers, which work at 200 pounds pressure, having been tested to 300 pounds by water pressure. There are six double ended and four single ended boilers, each 15 feet $7\frac{1}{2}$ inches in diameter, while the former are 20 feet long, and the latter are 10 feet $4\frac{1}{2}$ inches. The shellplates are $1\frac{9}{16}$ inches in thickness, and are quadruple riveted with $1\frac{1}{2}$ inch rivets. The front plate is flanged inwards. There are four furnaces in each end, and these have each separate combustion chambers. Thus there are in all 64 furnaces. These are of Fox's corrugated type and, in accordance with latest practice, they are slightly reduced in diameter towards the back, so that they may be readily withdrawn for repairs without injuring the front of the boiler. The flues are 3 feet 3 inches in diameter, of $\frac{19}{32}$ inch thickness of metal, and the furnaces, which have the ordinary fire bars, are 6 feet $10\frac{1}{2}$ inches long. There are 416 tubes in the single ended, and 832 in the double ended boilers, the total number of tubes in all boilers being 6,656. The number of stay tubes is 328 in each double ended boiler. The fire tubes are $2\frac{3}{4}$ inches in external diameter, and the thickness of metal 11 B.W.G., while the stay tubes are $2\frac{3}{4}$ inches in diameter and $\frac{1}{4}$ inch thick, the distance between the tube sheets being 7 feet. The tubes, by the way, are fitted with spiral retarders which have given good results in causing the hot gases to pass in a helical course through the tubes, and thus insure prolonged contact with the surface. The tube plates are $\frac{5}{8}$ inch thick. The diameter of the combustion chamber stays at the smallest base is $1\frac{3}{4}$ inches for the outside row, and $1\frac{3}{8}$ inches for the inside row, by 7 inches pitch. The total grate area is 1,144 square feet, and the total heating surface 40,320 square feet.

There are six safety valves on the double ended and four on the single ended boilers, all of 4 inches diameter.

The installation of boilers is equally divided between two water tight compartments. There are thus three double ended and two single ended boilers in each, and the installation is worked under Howden's system of forced draft, by which the air is heated before being passed into the furnace. The stokehold is open, and is specially well ventilated. It is divided longitudinally in the middle line by a thin plating or screen, which comes to within 6 feet of the heads of the stokers. The down air shaft is on the one side of this screen, and the other side is closed in at the top, excepting the intake for the forced draft fans. Thus the current of air is brought as near the stoking floor as possible—an arrangement which, like several others, is due to the long experience of Mr. Doran, the superintending engineer of the American Company. The eight fans—two for each stokehold—are of the Sturtevant type, driven by two cylinder engines, 8 inches by 6 inches stroke. The fans are 80 inches in diameter, draw the air from the top of the stokehold, and deliver it into the air heating tubes in the uptake, whence it passes to the space inside the furnace door, and thence through small holes to the fire. The system is too well known to require further description. There is bunker capacity for carrying 2,500 tons of coal, which will just equal eight days' consumption. There is a small bunker athwartship, between the engine room and the after boiler compartment, one between the two compartments, and a third at the fore end of the forward compartment. There is 40 feet of the length of the ship between each boiler compartment. There is a donkey boiler for supplying steam to the deck machinery.

There are two funnels, 11 feet 6 inches by 14 feet, the height being 100 feet from the grates.

Among the auxiliary machinery first reference may be made to the electric machinery. It is by the Electro Dynamic Company of Philadelphia. There are four dynamos, each coupled direct to high pressure engines, with two cylinders 12 inches in diameter by 10-inch stroke, and with a piston valve common to

both cylinders. They are four-pole machines, with compound wound Gramme ring armatures, each giving 360 amperes and 112 volts at 470 revolutions, and running 700 lights. Any of the machines may be used for any circuit. The ship is wired on the double wire system, and one feature is that the connections are all in water tight cases, while the distribution boxes are all water tight, having three compartments, for fuse, switching and binding, the fuse box only having a glass front. The circuit is subdivided into four sections, any or all of which may be worked separately. The lights are 16-candle power, and for cargo purposes, six are grouped in a bell shaped reflector, the connection to the mains being by a socket pipe in an india rubber covered casing. There are several motors for driving Sturtevant fans for ventilating the passenger decks, including two 9-horse power, two 7-horse power, and four 5-horse power machines. The motors are of the two-pole, Gramme ring type, and in addition there are two 10-horse power and one 5-horse power motors for the refrigerating plant for the ship's stores. They are of the same type as the other motors, but are series wound to admit of greater variation in the speed. The fan motors are shunt wound. There is also a motor for driving the pumps for the organ, placed in the gable of the arched well of the dining saloon. The motor, &c., is placed between the inner casing of the dome and the outer and much stronger casing. Electricity is also used for a "tell-tale" at the navigating bridge and in the chief engineer's room, to indicate the revolving speed of the engines. Acceleration in speed of the shaft increases the current passed to the tell-tale, and thus operates the indicator. The movements of the rudder are similarly recorded. On the rudder head is a pointer which is moved over a contact plate, completing a circuit at each point, and thus indicating the movement of the rudder on the dial at the captain's bridge.

For ventilating the compartments where passenger cabins are situated, there are four stations, each with two fans, one for exhausting and the other for supplying air. These fans are driven by electric motors, as already stated. The exhaust trunks are carried to each state room, while the supply fans discharge into

the corridors and passages, to pass thence through the jalousies of the doors. The fans, as a rule, are 5 feet in diameter, and may run to 470 revolutions. The air supplied may, in winter weather, be passed through a casing with a large series of steam pipes supplied direct from the boiler. There is a valve by which the amount of steam may be varied to suit any temperature of air desired. The radiator pipes are in five sections, each controlled by a valve. There is, however, no corresponding means of cooling the air. Possibly were some method adopted, greater success would attend the ventilation, especially in calm summer weather. Such a cooling process has been introduced in other vessels.

The steering of the ship is by gearing which in general arrangement is somewhat similar to that first introduced, if we mistake not, by Brown, of Edinburgh, and now much used in large British mercantile and Navy ships. The gear in the *St. Louis* was constructed by Messrs. Williamson, Philadelphia, and is actuated by Brown's telemotor. There is a right and left-handed screw, 8 inches in diameter and 10 feet long, on which run two nuts, from which are connecting rods to the crosshead on the rudder. The nuts are made in halves, so that should it be required they may be quickly removed. The revolving of the screw thus operates the nuts, and through the nuts the rudder. The engine for this purpose is horizontal, of the high pressure type, with two cylinders 14 inches in diameter by 12 inches stroke. The piston valve is operated direct by Brown's hydraulic telemotor, or by shafting from the deck above, through bellcrank levers. The crankshaft of the engine works gearing which is of brass with V-teeth made in halves, to admit of machine cutting, and thoroughly pinned together. Buffer springs are used to arrest the motion when the rudder is put hard over, and when released aid in bringing it back to amidships. Clutches throw the steam engine out or into gear, and similarly three handwheels may, when required, be geared up to the right and left handed screw. Moreover, there is a tiller on the rudder head, standing out above the right and left handed screw; by this the ship may be steered either by the interposition of the steam engine or hand gear, through wire ropes winding round a series of pulleys, and made fast to the

end of the tiller. A friction strap is provided to a horizontal pulley on the rudder head to take up the strain of the rudder while any change in the gearing is being made. The gearing, which is fitted with electric tell-tale as already described, is of massive design, and should stand much wear.

The vessel is fitted with the Hyde windlass in the forecastle, and there are two power and two speed capstans forward, and one power and two speed capstans aft on the poop, all of the same design, and supplied from the Bath Iron Works. The cylinders of the windlass are vertical, each 12 inches diameter by 10 inches stroke, with slide valves. The capstan engines are also vertical and not inverted, and the gearing is so arranged that either engine can drive windlass or capstans. The chain, it may be said, is $2\frac{3}{4}$ inches, the largest yet made in the States, but $\frac{1}{4}$ inch smaller than the *Campania's*. There are seven anchors, the weights being 105 hundredweight, 104 hundredweight, 79 hundredweight, 78 hundredweight, 39 hundredweight, 18 hundredweight and 10 hundredweight. They are of the Hall and Trotman construction. The vessel will carry about 1,500 tons of cargo, and there are six hatches, for which five winches have been supplied. These are of the Williamson type, with horizontal engines, the cylinders being 8 inches by 10 inches, with a 24-inch drum. On the boat deck there is a boat hoist with long shafts and double drum on either side. There are 16 ordinary boats, besides a number of collapsible boats and 16 rafts.

There are two refrigerating installations, one amidships in connection with the stores for ship's use, and one in the forecastle for cargo hold. Both are on the Kilbourn system. From the cold store there is an electric elevator. Part of the drum shaft is threaded for carrying a nut, which at the end of its travel releases the switch connection when the elevator has reached top or bottom. The connection is made by the half turning of a wheel on which the switch is mounted, until the switch is brought in contact with the gearing.

Kherson.—A twin screw steamer for the Russian Volunteer Fleet, built by Messrs. Hawthorne, Leslie & Co. She is of the following dimensions:

Length between perpendiculars, feet	455
over all, feet	500
Breadth, extreme, feet	54
Depth, feet	36
Draught, load, feet	24
Deadweight on above draught, tons	4,076
Bunker capacity, tons	1,300

Her engines are of the triple-expansion type, and are of 12,500 I.H.P. Steam will be furnished by twenty-four main and one auxiliary boiler of the Belleville type, each of eight elements, and working under a pressure of 250 pounds, which is reduced to 170 at the engines. The grate surface is 1,132, and the heating surface 36,000 square feet. The main boilers are arranged in three groups. The screws are of manganese bronze.

The contract requires a mean speed of 19.5 knots on a twelve hours' trial, during which the piston speed must not exceed 800 feet per minute.

Ohio.—Formerly the *Egyptian Monarch*, and now belonging to the Wilson Line, has recently been fitted with quadruple expansion engines and Belleville boilers by Earle's Shipbuilding and Engineering Company, Hull. The engines are of 1,640 I.H.P., and have cylinders 22½, 32, 45 and 64 inches diameter by 42 inches stroke, working at a pressure of 200 pounds. The boilers are four in number, and on trial had 185 square feet of grate, and 6,000 square feet of heating surface; but the grate surface has since been reduced to 112 square feet.

Hero.—This steamer was built by Earle's Shipbuilding and Engineering Company, Hull, for the well known Wilson Line. She is of the following dimensions: Length between perpendiculars, 217 feet; breadth, molded, 30 feet; depth of hold, 13 feet 8 inches; and 775 tons gross register. The engines are of 1,300 I.H.P., triple-expansion, the cylinders being 18½, 31 and 53 inches in diameter, and have a stroke of 33 inches. The boilers, two in number, are of Babcock and Wilcox's patent water tube type, and supply steam at a pressure of 200 pounds per square inch. They are 9 feet 6 inches wide, 10 feet long, and about 15 feet in height, having a total heating surface of 4,400 square feet, and a grate surface of 88 square feet. Each boiler has one furnace with two

doors and two ashpits. The lower tubes are 4 inches diameter, and the upper ones 2 inches diameter. By the adoption of these boilers it is calculated there is a saving of weight of from fifty to sixty tons. It is noteworthy that the boiler feeding arrangements are merely of the usual character for ordinary boilers, the ordinary feed pump being part of the main engines, and the auxiliary one of Pearn's duplex pumps. The engine room equipment includes a Kirkaldy's Compactum Evaporator, and one of the same maker's compactum filters. The trial trip, on June 7, was of a most successful character, the steam supply was constant and steady, and the mean speed of four runs with and against the tide, with the engines running at 108 revolutions, on the measured mile, at Whithernsea, was nearly 14 knots.

Turret Cape.—Another steamship fitted with two Babcock and Wilcox's water tube boilers, the *Turret Cape*, had a successful trial trip on June 8th. This vessel is a sister ship to the *Turret Crown*, and has a gross tonnage of 1,890 tons. Both vessels have been built to the order of Messrs. Petersen, Tate & Co., Newcastle-on-Tyne, by Messrs. Wm. Doxford & Sons, Limited, Sunderland, who are the inventors of the "Turret" design of steamships. The engines are of 1,100 I.H.P., working at 180 pounds per square inch. A modification in the boilers has been made by reducing the total grate area from 110 square feet to 83 square feet, by erecting fire brick divisions, namely, two on each boiler, so that there are now three furnaces on each boiler instead of one large furnace.

The engines are triple-expansion, with cylinders 21½, 36 and 59 inches diameter and a stroke of 39 inches. The hull is constructed on the Bell-Rockliffe system of joggled plating.

The trial trip was conducted as a progressive one, commencing with an engine speed of 40 revolutions per minute. The highest mean speed allowed on the measured mile at Whitley was 11.5 knots, with 68 revolutions per minute. During the trial the heat of the waste gases at the base of the funnel was carefully observed by means of a high grade nitrogen thermometer, and with readings taken every minute during the highest speed runs, the mean of the readings gave 455 degrees Fah. Unfortunately

time did not permit of a consumption trial, but it is confidently anticipated that the reduction of the grate area will be productive of increased economy in the fuel consumption.

The arrangements for feeding the boilers are of an ordinary character, the feed pump being driven off the main engine, while the auxiliary feed is an ordinary Worthington pump. A Yaryan patent evaporator of the latest type is fitted, having the brine pump worked from the main engine lever instead of having an independent pump, and gave every satisfaction, as also did Rankine's patent filter.

Zenith City.—The following description is taken from the "Marine Review:"

"This steel steamer, 400 feet long, is being built by the Chicago Ship Building Company for service in the iron ore, grain and coal trades on the lakes. The *Zenith City* is the first freight carrier in this country of large dimensions to be fitted with water tube boilers. They are of the Babcock & Wilcox Co.'s marine type. The engines to which these boilers are to furnish steam at 200 pounds pressure are of the vertical triple-expansion type with cylinders 23, 38 and 62 inches diameter and of 40 inches stroke.

The boilers each contain 3,000 square feet of heating surface and 72 square feet of grate. They are composed entirely of open hearth steel forgings and straight charcoal iron boiler tubes, not a pound of cast or malleable metal or a bent tube entering into their construction. The boiler consists essentially of two banks of tubes placed at an angle of 15 degrees from the horizontal and separated by a combustion chamber, the lower bank being composed of 4-inch tubes placed four rows high, and the upper bank of 2-inch tubes placed 11 rows high. All tubes are expanded at their ends into sinuous wrought steel front and rear headers, forged into shape by hydraulic pressure. The rear headers are connected at their upper ends by 4-inch tubes to a steam and water drum 42 inches diameter, and at their lower ends to a mud drum or blow-off connection. The front headers are suspended from a cross box supported by two front corner boxes. The cross box is in turn connected to the steam and

water drum by 4-inch tubes, completing the cycle for circulation, *i. e.*, from the drum down the rear headers towards the mud drum—where any sediment in the water is deposited—up the inclined tubes to the front headers, up the front headers to the cross box, and from the cross box to the drum. On account of the stagger given to the headers, the tubes are so disposed that the gases are entirely broken up and thoroughly mixed in their passage through the boiler.

Opposite the end of each tube is an opening, through which the tube may be examined and cleaned, or, when necessary, withdrawn and a new tube inserted. The hand hole plate and inside guard closing this opening are made from rolled plate and forged into shape by hydraulic pressure, the headers being flanged out to form the metal to metal seat under each hand hole cap. The inside guard is of such shape that should the $1\frac{1}{8}$-inch bolt holding the guard and cap in place break, only a leak would result. This same joint has been in constant use in stationary practice for years, and has given excellent satisfaction.

The boiler is encased on the sides with 4-inch tubes expanded into straight manifolds, the furnace sides being formed of square water boxes constructed of open hearth steel half an inch in thickness, doing away with all fire brick in contact with the fire, with the exception of the regulation bridge wall in the rear of the grate. These water box sides insure a cool casing, even when the combustion is forced to the rate of sixty pounds of coal per square foot of grate, and avoids clinkering and repairs. Against the side tubes is placed asbestos and 2 inches of magnesia block covering, the whole being held into place by sheet iron plates braced with angle irons and bolted to the foundations.

Following are some of the reasons urged in favor of the adoption of this boiler:

First. Reduction in weight for high steam pressure, the weight being 27 pounds per square foot of heating surface for 250 pounds pressure, against 75 pounds per square foot in Scotch boilers for 175 pounds pressure.

Second. Reduction of space occupied, and increased furnace capacity.

Third. Absolutely free circulation, enabling any amount of forcing that the fireman is capable of.

Fourth. Water sides to furnace, preventing serious radiation, obtaining a cooler fireroom, and avoiding clinkering of furnace sides and repair to brickwork.

Fifth. Absence of automatic devices of all kinds that are continually getting out of order and giving trouble, such as feed regulators, reducing valves, steam separators, etc.

Sixth. On account of the body of water carried in the steam and water drum at the water level, and the freedom of circulation, sudden fluctuations in the water level when forcing are eliminated.

Seventh. Steam space sufficient to obtain dry steam without the necessity of expanding from a higher to a lower pressure in order to evaporate the water in the steam.

Eighth. Increased ratio of heating to grate surface, thereby materially improving the economy.

Ninth. Ability to clean, renew or plug a tube through a hand hole of sufficient size opposite the end of same, without removing any other tube or pressure part, or cooling down the boiler other than blowing off the pressure.

Tenth. All joints are metal to metal, no gaskets of any kind being used. All joints exposed to products of combustion are expanded into bored holes, no screwed fittings being used.

Eleventh. Boilers of large units can be employed, thus doing away with an increased number of small boilers, multiplicity of fittings and additional apparatus.

Kingstown and Holyhead Mail Service.—Four new twin screw steamers are about to be constructed for the improved mail service between Holyhead and Kingstown. These vessels will be 371 feet long, 40 feet beam, 29 feet 3 inches in depth from hold to spar deck, and of 2,676 tons. The engines are to be triple-expansion and of 8,250 horse power. These vessels are for the City of Dublin Steam Packet Company. The service is to be twice daily in each direction, and four vessels must be built to meet the views of the Postmaster General, strict conditions and penalties being laid down to insure regularity and speed. The subsidy up to March 31, 1917, is to be £100,000 per annum, but

unless a year's notice be given, the contract will continue, but the sum will, after 1917, be £80,000, and the contract will be terminable on either side on twelve months' notice. A percentage of the passenger receipts, which is compounded at £2,000 per annum, must be paid to the Postal Department. Now as to penalties. The four boats must be complete and ready for service by March 1, 1897, or £50 must be paid for each day the vessels are behind time. The vessels must go on the service on April 1, 1897, or £250 must be paid for every day they are behind. Other penalties, for delay in starting and making the trips, are provided.

Cape Ann.—Was built by The Neafie & Levy Company, of Philadelphia, for the Boston & Gloucester Steamboat Company. The new boat is built throughout of steel, 185 feet long, 29 feet beam and 14½ feet depth of hold. She is propelled by a single screw, with compound engines, having cylinders 25 and 50 inches diameter by 30 inches stroke, steam being supplied by three Scotch boilers. The new boat is thoroughly modern and up to date in all her fittings and equipments and has the Williamson steam steering engines and American ship windlasses. A complete electric light plant is installed, and it is the intention of both owners and builders to have a steamboat equal to any afloat. She will run between Boston and Gloucester, Mass., and will be large enough to carry about one thousand passengers, in addition to what might be ordinary freight, and she is guaranteed to develop a speed of 16 knots when in service.

Messrs. Neafie & Levy were awarded the contract (their bid being $101,085) for the boat on account of agreeing to deliver her in five months' time, although they were not the lowest bidders. A penalty was to be exacted for each day over the time specified. The contract was signed the first week in January and the boat delivered in Boston the first week in June. She made the trip from Philadelphia to Boston in 46 hours, although no attempt was made to force her. The new steamer had a very satisfactory trip on the Delaware before she started around to Boston.

Chesapeake.—This steamer, launched on Wednesday, June 26,

from the shipbuilding yard of Messrs. David J. Dunlop & Co., Port Glasgow, was built for the Anglo-American Oil Company, London, for carrying petroleum in bulk. She will be the largest oil steamer afloat, her deadweight carrying capacity to Lloyd's freeboard being 6,000 tons, with a gross register of about 4,600 tons. The dimensions of the steamer are 385 feet over all, 370 feet between perpendiculars, 47 feet beam, 29 feet 3 inches in depth molded to upper deck. She is a three-deck vessel, and the hull is divided logitudinally into 18 compartments by transverse water tight bulkheads. There are 10 double tanks for carrying the oil, the longitudinal middle line bulkhead dividing each of the 10 tanks. To preclude the possibility of oil finding its way into the holds or engine and boiler space, a cofferdam, 4 feet long, is placed at each end of the two main oil divisions of the steamer. An important feature in the construction of the bulkheads is that all the caulking can be done in each alternate tank. The whole of the bulkheads dividing the oil tanks were subjected to a pressure of 20 feet head of water above the main deck, and withstood this unusual test in a highly satisfactory manner. The machinery consists of a set of triple-expansion single screw engines, having cylinders 27 inches, 43½ inches and 70 inches in diameter by 51 inches stroke. The oil pump machinery consists of two "Snow" duplex pump engines, 12 inches by 12 inches, one placed in the pump room aft, and one in the pump room forward. A noticeable point in the construction of this steamer is the placing of machinery in midships, necessitating the construction of an absolutely water tight tunnel for the main shafting. This tunnel is entirely cut off from communication with the engine room, the only access to it being obtained from the trunks leading from the poop deck, this precaution being considered necessary (in the event of any damage to the tunnel through the shaft breaking or any other cause) to prevent the access of oil or oil vapor to the engine room.

Georgic.—A twin screw steamer built by Messrs. Harland and Wolff, Belfast, launched on 22d of July. She has been built for the Oceanic Steam Navigation Company, and is intended to run in their cargo and live stock service between Liverpool and

New York, and is the thirty-fourth steamer constructed by Messrs. Harland and Wolff for the White Star Line, and the largest cargo steamer afloat. Her tonnage is about 6,580 net and 10,000 gross. She will be fitted for the accommodation of about 900 head of cattle on the upper and bridge decks, and will, in addition, have permanent stalls of a most perfect kind for a large number of horses in the center of the upper deck. The machinery for the vessel, which has been constructed in the engine works of the builders, consists of two sets of triple-expansion four-cylinder engines of the most modern type. The vessel will be fitted throughout with the electric light. Her length is 557 feet, beam, 60 feet, and depth, 40 feet. The two screws overlap each other slightly in the hole where the deadwood is cut away.

Germanic.—This steamer, of the White Star Line, was built at Belfast, in 1875, by Messrs. Harland and Wolff, and from that time until the end of last year, was regularly at work on the Atlantic, and has made no less than 211 round voyages, 422 passages across the Atlantic, or a distance of more than 1½ million statute miles. The original engines, after nearly twenty years' work, have now been taken out, as well as the boilers, and have been replaced by triple-expansion engines of about 6,000 I.H.P. The ship has besides undergone a thorough overhaul, and many improvements have been introduced, all the work being effected by Messrs. Harland and Wolff, Limited. The *Germanic*, after a satisfactory trial and adjustment of compasses, left Belfast for Liverpool on May 9th. On her first trip to New York, she broke all her previous records to that port. She made the passage in six days twenty-three hours and twenty-seven minutes. Her day's runs were 400, 396, 405, 411, 420 and 326 knots, covering a total distance of 2,779 miles. Her previous record was seven days ten hours and thirty-five minutes.

Sumatra.—This steamer, built by Messrs. Alex. Stephen & Sons for the P. & O. Steam Navigation Co., was launched June 25. She is 400 feet long, 46 feet 6 inches beam, and has a depth of hold of 31 feet. Her gross tonnage is about 4,650 tons, and

her deadweight capacity about 5,900 tons. Her construction complies with the Admiralty regulations for transport service. There are seven water tight bulkheads extending to upper deck. She is handsomely fitted for passenger service. The engines are triple-expansion, with cylinders 28, 46 and 77 inches diameter, and a stroke of 54 inches. Howden's forced draft system is used, and the boilers work at a pressure of 180 pounds per square inch. There is a complete system of vertical compound pumping and auxiliary engines. Electric lights are fitted throughout the ship.

YACHTS.

Free Lance.—This steam yacht was constructed at the yard of Lewis Nixon, Elizabethport, N. J., and is 108 feet on water line, 137 feet from point of figurehead to taffrail, 20 feet beam, and 6 feet 9 inches draught. The cross section of the *Free Lance* is different from all other steam yachts. The keel is 2 feet wide, and flat at the bottom, and the form of the section is that of a sailing yacht, a sharp dead rise, and very little bilge, with a flared side. The forefoot is entirely cut away, and the bow is carried out with a long head. The stern has a long overhang and a full load water line. The vessel is built of steel. The plating is lap work, and the lines of plating have received much attention. There will be two houses on deck. The forward one will be used as a pilot house and rooms for officers. Below will be the galley and quarters for the crew. Aft will be the staterooms and dining room, and the after house will also be used as a dining room. There is a triple-expansion engine of about 600 I.H.P., with cylinders 11, 17 and 29 inches in diameter, and a stroke of 20 inches. The boilers will be of the Almy water tube type, with 52 square feet of grate surface.

Veglia.—This large screw steam yacht was built by Messrs. D. and W. Henderson & Co., Partick, and was launched on June 24. The dimensions are: Length over all, 275 feet; breadth, 30 feet 6 inches; depth, 20 feet. The vessel is classed as 100 A1, in Lloyd's yacht registry. The machinery has been constructed by the builders' firm, and consists of a set of triple-expansion engines and a very large boiler fitted with forced draft. The cylinders are 23 inches, 38 inches and 64 inches in diameter, with a stroke of 36 inches, and the working pressure is 160 pounds.

Catania.—Another steam yacht by the builders of the *Veglia*, was launched on June 6th. She is classed in Lloyds, and is of

the following dimensions: Length over all, 225 feet; breadth, 26 feet 6 inches; depth, 16 feet 6 inches. Externally the vessel has a very graceful appearance. A novelty in the design of the vessel is a shade deck, extending nearly three-fourths the length and from side to side of the vessel, covering the deck houses and machinery casing. This will furnish a long unbroken promenade not usually obtained in a steam yacht. It is supported at the sides by stanchions above the main rail. The engines are triple-expansion with four cylinders, 18 inches, 28½ inches, and two of 32 inches diameter, with a stroke of 27 inches. There is a large single ended boiler, fitted with forced draft.

Urania.—This steam yacht was launched on Friday, June 7, from the yard of Messrs. James and George Thomson, Clydebank. She is 200 feet long, 26 feet 3 inches broad and 16 feet 6 inches deep, and has a tonnage of 550 tons, and has been built to the highest class of the British Corporation. The vessel is specially intended for long ocean cruises, and has a coal capacity of more than 200 tons, which will enable her to steam for 6,000 knots without coaling, at a speed of 10 knots. A large electric launch, which will be capable of steaming for a distance of 100 knots, and four other boats are supplied.

Monsoon.—The trial trip of this steam yacht took place on the measured mile at Stokes Bay on July 4. She was built by Messrs. Day, Summers & Co., Southampton. Her dimensions are: Length, 138.5 feet; breadth, 19.125 feet; depth, 11.1 feet; tonnage, yacht measurement, 235; tonnage, gross register, 171. Engines of the compound type have been fitted, the diameters of the cylinders being 15½ inches and 30 inches by 23 inches stroke. The boiler is 10 feet in diameter, the length 9 feet, and the working pressure 100 pounds. The total heating surface is 856 square feet, and the total grate area 38 square feet. The propeller has four blades 8 feet in diameter, 12 feet 6 inches pitch, and 18 square feet surface. The draught on trial was, forward, 8 feet 7¾ inches; aft, 10 feet 4¾ inches; mean, 9 feet 6¼ inches, the displacement being 280 tons. The weights on board included coal, 43 tons; water, 6¾ tons; ballast, 30 tons. The mean steam pressure was 96 pounds, vacuum, 25 inches, and revolutions, 110.

The mean speed on four runs was 11.014 knots, and the mean indicated horse power, 266.

Oneonta.—This steam yacht was launched by the Delaware River Iron Shipbuilding and Engine Works, Chester, Pa., on July 23d. She is 136 feet over all, 18 feet beam and 6 feet draught, is beautifully modeled, and in appearance resembles a torpedo boat more than a steam yacht. There is a triple-expansion engine of 800 horse power, and a Thornycroft tubulous boiler built in this country, supplying steam of a pressure of 250 pounds to the square inch under forced draft. The speed will be about fifteen knots. The propeller is 5 feet 9 inches in diameter. There is an independent circulating pump. There is only one mast, situated abaft the engine room. Her deck fittings, instead of being of brass, as is usual, are of white metal, so as to be perfectly rust proof. The crew's quarters are below the main deck, forward of the boiler space.

Thespia.—This steel steam yacht was launched from the works of Messrs. Wm. Cramp & Sons, Philadelphia. She is 174 feet 5 inches long on the water line, 195 feet length over all, 23½ feet beam, 13 feet depth of hold and 10 feet draught. The engines are compound, with cylinders 22 and 42 inches diameter by 24 inches stroke. Steam will be supplied by two boilers 10 feet 9 inches long and 11 feet in diameter. All the engine and other auxiliaries will be of the most approved type. The yacht when finished will be an important addition to the New York Yacht Club's already splendid fleet of steam yachts.

Huntress.—This steam yacht was launched at the yards of her builders, Charles L. Seabury & Co., Nyack-on-Hudson, at 20 minutes past midnight, on June 29th. The *Huntress* is 120 feet over all, 97 feet on load water line, 16 feet beam, 9 feet depth, 6 feet 6 inches draught. She has excellent accommodations. The engines are triple-expansion, and there is a Seabury safety water tube boiler of latest type. The guaranteed speed in contract is 16 miles per hour for three consecutive hours. She is schooner rigged, flush deck.

Peregrine.—This steam yacht was built by the Bath Iron Works, of Bath, Me. She is of the following dimensions: Length over

all, 158 feet 3 inches; on load water line, 131 feet; beam, extreme, 23 feet; depth of hold, 13 feet; mean draught, 10 feet; extreme draught, 10 feet 9 inches. There is a large mahogany deckhouse 72 feet long, with an average width of about 13 feet. Large circular sliding lights or air ports, 16 inches in diameter, give light and air to the living compartments of this deck house, and these lights have proved a great improvement over the ordinary swinging ones. A donkey boiler will be placed in the boiler room for steam heating and auxiliary purposes. A Williamson steam steerer, a Hyde hand screw steerer and a Hyde patent steam windlass are also fitted. The vessel will be lighted throughout by electricity, the dynamo being in the engine room, and a 12-inch search light and display lights for the rigging will be fitted. There will also be efficient telephone and electric bell communication between various parts of the boat. She will carry three small boats and a 23-foot naphtha launch. She is rigged as a two-masted schooner, the total sail area being about 3,500 square feet. There is a vertical triple-expansion engine, with cylinders 14, 21 and 34½ inches diameter, and a stroke of 22 inches. Piston valves are used throughout; the high pressure cylinder is between the intermediate, which is forward, and the low pressure. The condenser forms part of the framing at the back of the engine, the cylinders being well supported and braced by steel columns. The propeller is of manganese bronze, four-bladed, with a diameter of 8 feet 3 inches and a pitch of about 10 feet. There are two Almy water tube boilers, built for a working pressure of 185 pounds each, occupying a space 83 inches long, 83 inches wide and 104 inches high. The grate surface is 65, and the heating surface about 2,500 square feet. The designed indicated horse power is 800, and the speed over 14 knots.

Calypso.—This steam yacht is schooner rigged, and was designed and built by the Atlantic Works at East Boston, Mass., during the past year. The hull is of wood, and the principal dimensions are: Length on load water line, 102 feet; beam, 17 feet; draught, 7 feet 4 inches, with tanks and bunkers full and all stores on board.

She has one deck house of mahogany, located forward.

Her engines are vertical, inverted, direct acting compound, with cranks set at 90 degrees, and cylinders 12 and 22 inches diameter, and a stroke of 16 inches. The main valves are of the piston type and are actuated by a Stephenson link motion. The cylindrical surface condenser has 400 square feet of cooling surface. There are two independent feed pumps and a combined air and circulating pump, all of the Blake type. There is a Hancock locomotive inspirator and a bilge ejector. There is an auxiliary suction pipe and valve from the circulating pump to the bilge for use in case of emergency. The boiler is of the Almy double water tube type, the working pressure being 130 pounds. The entire machinery is below deck, the smoke stack and whistle and escape pipes only appearing above deck.

The electric plant, located in the engine room, is very compact. It consists of a multipolar dynamo driven direct by a compound engine with cylinders $2\frac{3}{4}$ inches and 5 inches diameter and $2\frac{1}{2}$ inches stroke, and has a capacity to furnish current for sixty 16-candle power lamps at a pressure of 75 volts. There is a storage battery of sufficient capacity to run thirty lights for nine hours, which can be charged in the day time when steam is up, thus dispensing with the necessity of keeping up steam and running the dynamo at night. There is a Huntington search light of a capacity of 4,000 candle power, which can be run either from the storage battery or direct from the dynamo.

Her maximum speed is about 15 miles per hour, and her actual continuous speed under natural draft, as shown on her cruises from port to port, is about 14 miles. She went into commission the 18th day of May, and since then has made several cruises along the coast, some of them being in very severe weather. She has proved remarkably able and comfortable under all circumstances.

BOOK REVIEW.

AMERICAN STEAM VESSELS, by Samuel Ward Stanton; Smith & Stanton, New York.

The engineers and shipbuilders of the United States owe a debt of gratitude to Mr. Samuel Ward Stanton for his publication with the above title, representing as it does a world of patience, labor and research, and which enables one to note at a glance the gradual evolution of the floating palaces on our lakes, rivers and sounds, like the *Priscilla* and *Northwest;* the ocean greyhounds, like the *St. Louis;* and the battleship and fast cruiser, like the *Indiana* and *Minneapolis*, from Fulton's *Clermont* and *Demologos*.

The book also is of great service in calling to mind the names of the early engineers and constructors who, starting with little or nothing to guide them, by their own energy and ability, in spite of difficulties and discouragements, made a brilliant success of what in less able hands would have been but a dismal failure, and, by their solution of the problem of steam navigation, were no small factors in the progress and development of the country.

We of to-day, accustomed to 100-ton steam hammers and power tools that can take in and handle any part of the largest marine engine, are apt to overlook the difficulties experienced by the earlier Engineers, when shafts had to be forged by tilt hammers that now appear ridiculously small for the work, and valve seats faced off by securing the cylinder alongside of the planer and traversing the tool forward and backward by an angle plate bolted to the platen, the feed being in most cases regulated by hand. The earlier air pumps were in many instances staved, like a barrel, and more perfect work and exact fittting could not be turned out to-day.

In some of the very earliest steamers we see the same beauty of form and grace of outline that have since made the American model famous the world over; we see too how the river boat

engine, starting with the "grasshopper" on the *Clermont*, changed into the crosshead or square engine, and then into the overhead beam, which, in the hands of its skillful designers, became a marvel of strength and lightness, combined with perfect working.

The artistic beauties of the book are apparent on the most cursory examination; its historical value becomes more apparent the more closely it is studied, and it should have a place in the library of every one interested in the development, the progress or the present condition of American shipping.

OBITUARY.

EZRA J. WHITAKER.

Chief Engineer E. J. Whitaker was born in North Adams, Mass., April 12, 1839. He entered the Navy as a Third Assistant Engineer, February 21, 1861, was promoted to Second Assistant, December 17, 1862; to First Assistant, December 1, 1864; and on June 6, 1873, was commissioned a Chief Engineer.

His tour of sea duty comprised seventeen years of cruising on many vessels, including his service during the late war.

His last cruise was on the North Atlantic Station as Chief Engineer of the *Philadelphia.*

Among the more important duties on which he had been engaged while on shore was his service at the Navy Yard, Boston, in 1872–'74, and as member of Board for the Inspection of Merchant Vessels, at New York. He was detached and placed on the Retired List on May 8, 1895, having the relative rank of Commander.

He died at the age of 56, at Sackett's Harbor, N. Y., August 21, 1895.

ROBERT B. HINE.

Chief Engineer Robert B. Hine, U. S. Navy, was born in Durham, England, February 6, 1841. He entered the Navy as a Third Assistant Engineer, August 24, 1861; was promoted to Second Assistant, April 21, 1863; to First Assistant, October 11, 1866; and attained the rank of Chief Engineer on the 14th of December, 1882.

Considerably more than half of his career in the Navy was spent at sea, he having served with efficiency and zeal for eighteen years on vessels which cruised in many parts of the world. His last active service was on the *Concord.*

His shore service comprised duty at the Bureau of Steam Engineering, and as Member of Board of Naval Examiners at Washington, D. C.; his last term of shore duty being at the Quintard Iron Works, where he was engaged in preparing the *Concord* for sea.

Retiring on February 20, 1893, with the relative rank of Lieutenant-Commander, he lived a little over two years, and died at Washington, D. C., on the 27th of June, 1895, at the age of 54.

WM. W. HEATON.

Chief Engineer William W. Heaton was born in New York, N. Y., on May 23, 1839. Entering the Navy, December 2, 1861, as Third Assistant Engineer, he was promoted to Second Assistant, September 8, 1863; to First, October 11, 1866, and to Chief Engineer, January 26, 1886, with the relative rank of Lieutenant Commander.

His duty at sea extended over more than fifteen years, and included service on all stations. His last cruise was on the *Newark*, on the South Atlantic Station.

His shore service included duty at the Navy Yards New York and Norfolk, Member of Board for the Inspection of Foreign Vessels, and as Inspector of Machinery of Government Vessels being built at the Quintard Iron Works 1890–93.

While on the *Newark* he became seriously ill, was detached and sent to the Naval Hospital, New York, and subsequently ordered to appear before a retiring board.

He died at Naval Hospital, New York, on May 31, 1895, at the age of 56, before being transferred to the Retired List.